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FIRE RESEARCH ABSTRACTS AND REVIEWS. VOLUME 17, NUMBERS 1-3.(U)

1975 R M FRISTROM

DCPA01-76-C-0289

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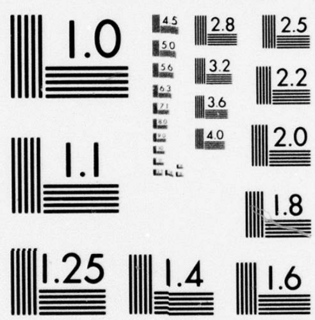
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LEVEL II (a)

Volume 17 1975 Numbers 1, 2, 3

Fire Research Abstracts and Reviews

National Academy of Sciences

FIRE RESEARCH ABSTRACTS AND REVIEWS

Robert M. Fristrom, *Editor*

Geraldine A. Fristrom, *Associate Editor*

The Committee on Fire Research

FIRE RESEARCH ABSTRACTS AND REVIEWS abstracts papers published in scientific journals, progress reports of sponsored research, patents, and research reports from technical laboratories. At intervals, reviews on subjects of particular importance are also published. The coverage is limited to articles of significance in fire research, centered on the quantitative understanding of fire and its spread.

Editor: Robert M. Fristrom, Applied Physics Laboratory
The Johns Hopkins University, Laurel, Maryland

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Volume 17, #1,2,3	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 FIRE RESEARCH ABSTRACTS AND REVIEWS. Volume 17, Numbers 1-3.		5. TYPE OF REPORT & PERIOD COVERED 9 Abstract Journal, 1975
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 ~~Editor~~ Robert M. Fristrom Applied Physics Laboratory, Johns Hopkins University		8. CONTRACT OR GRANT NUMBER(s) 15 DCPA 01-76-C-0289
9. PERFORMING ORGANIZATION NAME AND ADDRESS National Academy of Sciences 2101 Constitution Ave. NW Washington, DC 20418		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Civil Preparedness Agency Washington, D.C. 20301		12. REPORT DATE 11 1975
		13. NUMBER OF PAGES xxiv + 375
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 402p.		15. SECURITY CLASS. (of this report) UNC
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fire Research, International
Fire Protection, International

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This journal contains articles on the National Bureau of Standards program in fire research, mine fire problems, general fire problems, a review of fire related journal literature, as well as numerous abstracts of articles on fire research and protection published throughout the world.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

090 620 LB

Volume 17 Numbers 1, 2, 3

Fire Research Abstracts and Reviews

Committee on Fire Research
Commission on Sociotechnical Systems
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D. C.
1975

FIRE RESEARCH ABSTRACTS AND REVIEWS is published by the Committee on Fire Research of the Commission on Sociotechnical Systems, National Research Council. It is supported by the Defense Civil Preparedness Agency, the U.S. Department of Agriculture through the Forest Service, the National Science Foundation, the National Bureau of Standards, and the National Fire Prevention and Control Administration. The opinions expressed by contributors are their own and are not necessarily those of the Committee on Fire Research.

Library of Congress Catalog Card Number 58-60075 rev

Back issues of FIRE RESEARCH ABSTRACTS AND REVIEWS are available through the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22151. Purchases require mention of the AD number assigned:

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9	— AD	769-530 ([redacted] Cumulative Index for Volumes 1-9) AD-769534
10	— AD	769-531
11	— AD	769-532
12	— AD	769-533
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15, No. 1	— AD	A-025-493
No. 2	— AD	A-025-494
No. 3	— AD	A-025-495

Current issues, as available,
distributed without charge by the
Committee on Fire Research
National Academy of Sciences—National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

FOREWORD

This marks the second consolidated yearly issue of FIRE RESEARCH ABSTRACTS AND REVIEWS. It results from an effort to regain currency in abstracting and publishing. We hope to return to our original publishing schedule with the next volume.

The issue contains three review articles. The first is a description of the program of the Center for Fire Research of the National Bureau of Standards written by the staff. This program is directed by Dr. John W. Lyons. The second article describes the Fire Problems Program of the Applied Physics Laboratory, The Johns Hopkins University, written by Dr. Walter G. Berl, Dr. Robert M. Fristrom, and Mr. Byron Halpin. These descriptions of two multidisciplinary fire research programs are the first of what we hope will become a series of portraits of fire research efforts in this country and abroad. Your editors are seeking concisely written descriptions of current fire programs.

The third article is entitled "Application of Fire/Gas Sensor Detection Technology to Metal and Non-Metal Mine Fire Problems" by Dr. J. A. Wagner, Dr. A. Tookson, and Dr. M. Hertzberg. This presents a state-of-the-art survey of mine fire detection problems.

We continue the fire journal title feature entitled "Fireliter," which was introduced in the previous issue. This has proved useful and we plan to continue it under the direction of Mr. Boris Kuvshinoff of the Applied Physics Laboratory, The Johns Hopkins University.

During this year the National Fire Prevention and Control Administration has continued to build momentum and staff. The President appointed an administrator, Mr. Howard Tipton, whom many will remember as the able Executive Director of the Presidential Commission on Fire Prevention and Control. The President has also appointed a Deputy Administrator, Mr. David Lucht, who was the State Fire Marshal of Ohio. The final appointment to the Administration is Mr. David McCormack, the Superintendent of the Fire Academy. We wish the Fire Administration staff well in this critical time of initial organization.

This has been a year of focusing and growth for the programs at the Fire Center of the Bureau of Standards. There has been a climate of increased cooperation between federal agencies in the area of fire. We hope this trend continues and that this year will have marked a significant turning point for fire research in this country.

The responsibility for the Fire Research Program of the RANN program of the National Science Foundation has been transferred to the new Fire Administration. Fortunately for continuity in the program, the transfer was accompanied by

a transfer of the program manager, Dr. Ralph Long*, whose wide experience and wise counsel have been a source of strength in fire research.

As a result of an agreement between the Federal Trade Commission and the foamed plastics industry, a new research foundation entitled the Products Research Committee, has been established on the flammable hazards of foam plastics. The Board of Trustees are:

The Foundation will sponsor research in various areas of flammable hazards of foamed polymers. Details of the program and copies of the "Request for Proposal" can be obtained from the chairman,

Dr. John W. Lyons
Products Research Committee
Building 225, Room B-142
National Bureau of Standards
Washington, D.C. 20234

This represents a compromise that substitutes a research program for a prolonged legal battle. Both society and industry should benefit from this rational compromise and we wish the committee well in their five-year effort. Both the Federal Trade Commission and the plastics industry are to be complimented for their far-sighted attitude in this matter.

ROBERT M. FRISTROM
Editor

*The untimely death of Dr. Long in June 1976 was a great loss to the fire field. Your editor feels the deep personal loss of a good friend and wise counselor.

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PROGRAMS OF THE CENTER FOR FIRE RESEARCH, NATIONAL BUREAU OF STANDARDS

INTRODUCTION

On October 29, 1974, President Ford signed into law the Federal Fire Prevention and Control Act of 1974. This legislation is the direct result of the findings of the National Commission on Fire Prevention and Control that America's fire losses are disgraceful and totally unacceptable to a country whose level of technology and human resources is the highest in the world.

The Federal Fire Prevention and Control Act responds to the nation's fire problem through the establishment of two agencies within the Department of Commerce. The first of these, the National Fire Prevention and Control Administration (NFPCA) focuses on broad areas of the fire problem, principally the need for improved fire experience data; more effective public education programs; a national fire academy; and improved technology for fire prevention and control. The second agency, the Fire Research Center, was established within the Commerce Department's National Bureau of Standards (NBS). In contrast to NFPCA, the Fire Reseach Center focuses principally on one aspect of the fire problem—developing the basic technical knowledge of fire and its effects necessary to reduce fire losses. The National Bureau of Standards has been involved in fire research for many years; locating the Center at NBS builds on existing research expertise.

The Fire Research Center is charged with developing an understanding of fundamental processes of fire, including its physics and chemistry; its behavior, spread, and growth in buildings; the fire hazards arising from transportation of combustible fluids and materials; and design concepts for increased fire safety in the built environment. The Congress also authorized the Fire Research Center to carry out investigations into the biological, physiological, and psychological factors affecting the victims of fire. In particular, the biological and physiological effects of toxic substances on fire victims and the psychological and motivational characteristics induced either by fire stress or fire trauma are to be systematically studied for the first time. Identifying the priorities for the Center's program as well as disseminating its results to the user community are joint responsibilities of NFPCA and the Center. The following sections describe the efforts aimed at reducing fire losses and the various program elements of the Center.

FIRE SCENARIOS AND INTERVENTION STRATEGIES

In developing a plan to cut the losses due to unwanted fire, it is essential to relate the planned research to the most probable fire situations so as to increase the likelihood of preventing such fires.

Fire Scenarios

Although each fire is unique, there are important common characteristics. A few types of ignition sources cause a large majority of fires; examples are

matches, cigarettes, and defective electrical equipment. Similarly the types of products or materials ignited are relatively few. It is possible to describe the physical aspects of an unwanted fire in terms of combinations of six characteristics:

1. Type of loss — death, injury, and/or property
2. Type of occupancy — residence, industrial, etc.
3. Time — day or night
4. Ignition source — matches, electrical appliances, etc.
5. Spreading agent — apparel, furnishings, etc.
6. Direct cause of loss — smoke and/or gas and/or heat and/or flame

For example, a death caused by smoking in bed can be described as follows:

1. Death
2. Residence
3. Night
4. Smoking
5. Furnishings
6. Smoke and gas

This listing of factors we term a fire scenario. Figure 1 illustrates the possibilities. Using a modified Delphi approach to identify the most important scenarios, the senior staff of the Center selected 14 scenarios (Table 1) that represent the types of fires toward which the Center's program is to be directed.

TABLE 1

The Top Fire Scenarios as Estimated by the Center Staff

	Description
1.	Death & Injuries/Residence/Night/Smoking, Lighters, Matches/Furnishings/Smoke & Gas
2.	Death & Injuries/Residence/Day/Heating & Cooking Surface/Apparel/Heat & Flame
3.	Death & Injuries/Independent/Day/Lighters or Matches/Apparel/Heat & Flame
4.	Property/Commercial & Industrial/Night/Arson/Flammable Fluids/Heat & Flame
5.	Death/Institutional/Night/Lighters or Matches/Furnishings/Smoke & Gas
6.	Death/Transportation/Day/Other/Flammable Fluids/Heat & Flame
7.	Death/Residence/Night/Electrical/Furnishings & Structural/Heat & Flame & Smoke & Gas
8.	Death & Injuries/Residence/Night/Smoking, Lighters & Matches/Furnishing/Heat & Flame
9.	Death/Commercial/Day/Flame/Flammable Fluid/Heat & Flame
10.	Property/Industrial/Day/Flame/Flammable Fluids/Heat & Flame
11.	Death/Industrial/Day/Arson/Flammable Fluids/Heat & Flame
12.	Property/Industrial/Night/Flame/Flammable Fluids/Heat & Flame
13.	Deaths & Injuries/Independent/Day/Flammable Fluid/Apparel/Heat & Flame
14.	Property/Residence/Day/Heating & Cooking/Finish & Furnishings/Heat & Flame

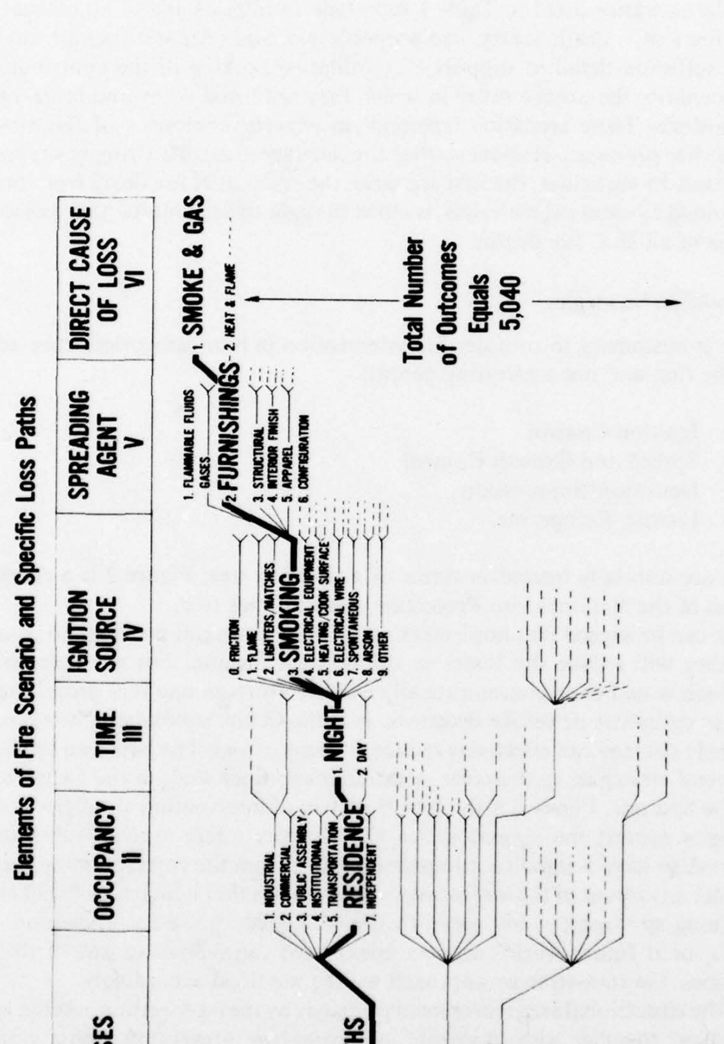

FIGURE 1 Elements of fire scenario and specific loss paths.

The scenarios listed in Table 1 represent an interleaving of all categories of direct fire loss — death, injury, and property loss. Since fire statistics are unavailable in sufficient detail to support a quantitative ranking of the contribution of each scenario, the precise order in which they are listed is, by and large, of little consequence. These scenarios represent an experts' consensus of the most important fire problems. However, what fire data are available strongly support the consensus. In particular, the first scenario, the residential fire death from furnishings ignited by smoking materials, is alone thought to account for approximately a quarter of all U.S. fire deaths.

Intervention Strategies

It is customary to consider fire intervention in four categories, three addressing the fire, and one addressing people:

- Ignition Control
- Spread and Growth Control
- Detection/Suppression
- Escape, Refuge, etc.

These are normally treated in terms of a decision tree; Figure 2 is a condensed version of the National Fire Protection Association's tree.

It can be argued that implementing the four strategies provides no guarantee that they will reduce fire losses in the optimal fashion. For example, another approach would be to concentrate all research efforts in one very promising area, such as sprinklers or smoke detectors. It is the Center's judgment, however, that no single strategy can effectively reduce all areas of loss. The balanced application of several strategies is, therefore, a rational appraoch and, in the Center's view, it is the best one. Figure 3 is the payoff matrix of intervention strategies and substrategies against the scenarios. An "X" denotes where a given substrategy is expected to have a significant impact on losses from the corresponding scenario. Another advantage of the multistrategy approach is that it increases the likelihood of turning up some key, but presently unanticipated, fire safety innovation. If this occurs, or if future work uncovers unexpected capabilities in one of the other strategies, the four-strategy approach will be modified accordingly.

The educational area represented primarily by the intervention column labeled "behavior" together with education in general (fire prevention) and a variety of policy matters (such as insurance laws and taxation powers) are not easily modified by technology. Educational concepts are well developed, but high fire losses persist; thus it is likely that new techniques of education specifically for fire prevention must be developed. Indeed, Congress has recognized this shortcoming by establishing a section of the National Fire Prevention and Control Administration to deal with this problem.

Consideration of the intervention strategies reveals certain ones that fall outside the NBS area of responsibilities. These excluded activities fall into two categories:

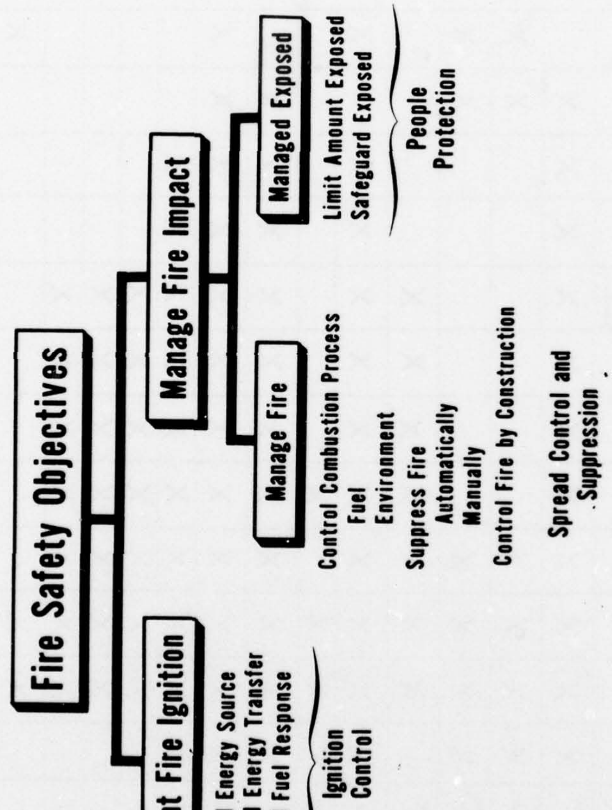

FIGURE 2 Condensed version of the National Fire Protection Association's tree.

INTERVENTION STRATEGIES / SCENARIOS	IGNITION CONTROL			CONTROL OF FIRE SPREAD			DETECTION/ SUPPRESSION/ FIRE CONTROL		DIRECT MEASURES FOR PEOPLE PROTECTION			
	Material Selection	Controlling Design	Behavior	Material Selection	Passive Design Concepts	Active Design Concepts	Automatic Detection Devices & Systems	Automatic Fire Suppression Devices & Systems	Detection Alarm, & Communication	Means of Escape & Rescue	Human Response to Emergency Stresses	Protection by Materials
Death & Injuries/Residence/Night/Smoking, Lighters, Matches/Furnishings/Smoke & Gas	X	X	X	X	X	X	X	X	X	X	X	
Death & Injuries/Residence/Day/Heating & Cooking Surface/Apparel/Heat & Flame	X	X	X	X							X	X
Death & Injuries/Independent/Day/Lighters or Matches/Apparel/Heat & Flame	X	X	X	X							X	X
Property/Commercial & Industrial/Night/Arson/Flammable Fluids/Heat & Flame		X	X	X	X	X	X	X				
Death/Institutional/Night/Lighters or Matches/Furnishings/Smoke & Gas	X	X	X	X	X	X	X	X	X	X		X
Death/Transportation/Day/Other/Flammable Fluids/Heat & Flame	X	X	X		X							
Death/Residence/Night/Electrical/Furnishings & Structural/Heat & Flame/Smoke & Gas	X	X	X	X	X	X	X	X	X	X	X	
Death & Injuries/Residence/Night/Smoking, Lighters & Matches/Furnishing/Heat & Flame	X	X	X	X	X	X	X	X	X	X	X	X
Death/Commercial/Day/Flame/Flammable Fluid/Heat & Flame	X	X	X	X	X	X	X	X	X	X		
Property/Industrial/Day/Flame/Flammable Fluids/Heat & Flame		X	X	X	X	X	X	X				
Death/Industrial/Day/Arson/Flammable Fluids/Heat & Flame		X	X	X	X	X	X	X				
Property/Industrial/Night/Flame/Flammable Fluids/Heat & Flame		X	X	X	X	X	X	X				
Deaths & Injuries/Independent/Day/Flammable Fluid/Apparel/Heat & Flame		X	X									X
Property/Residence/Day/Heating & Cooking/Finish & Furnishings/Heat & Flame	X	X	X	X	X	X	X	X	X		X	

FIGURE 3 Matrix of technical intervention strategies and the fourteen scenarios.

1. Areas outside of traditional NBS expertise
2. Areas specifically mentioned in the 1974 Federal Fire Prevention and Control Act but appearing elsewhere than Section 18

For example, the development of new materials is primarily a province for private industry, and the development of improved equipment for use by the fire services is a responsibility of the National Fire Prevention and Control Administration under Section 18 of the National Fire Prevention and Control Act of 1974.

Relating Program Elements to Intervention Strategies

Table 2 shows the relationship between the intervention substrategies and the operating units of the Center. These operating units are organized around traditional disciplines, such as chemistry, or around the study of a particular portion of the fire problem, such as fire control in construction. Note that, with the exception of library support, no program impacts all twelve strategies. Conversely, no substrategy has exclusively elements of any one program. The structure of each row of the matrix, that is, of each program, is discussed in the following section.

RESEARCH PROGRAMS

Information and Hazard Analysis

This program provides library support for the entire Center in close coordination with the library functions of the Fire Administration. Its principal programmatic responsibility is fire hazard analysis. Hazard analysis involves combining fire experience data, in-depth accident case studies, and chemical laboratory analysis to identify patterns of fire hazard, both of materials and products. In some cases, output is the identification of research priorities for other programs. In others, it is a support function, especially under Sec. 7 of the Consumer Product Safety Act (CPSA), carried out at the request of the Consumer Product Safety Commission (CPSC).

Chemistry

The chemistry program focuses on characterizing the molecular processes of combustion. These include thermodynamic and kinetic studies of combustion phenomena; spectroscopic identification of short-lived chemical intermediates present in flames; and experimental investigations of the chemical basis of "flash fires." These studies form the basis for critical evaluation of flammability tests, such as the oxygen index test. They also are designed to help in identifying the mode of action of chemical fire retardants.

Physics and Dynamics

The principal thrust of this program is to characterize the growth of fire in a

TABLE 2

Relationship Between Center Programs and Intervention Strategies

	Suppression Detection Fire Control	Direct Measures for Escape, Refuge and Protection				
	Automatic Detection	Automatic Suppression	Detection Alarm & Communication	Escape & Rescue	Human Response to Stress	Protection by Materials
Information and Hazard Analysis	*Library	*Library	*Library	*Library	*Library	*Library
Chemistry	—	*Combustion Chemistry	—	*Flash-Fire Studies	—	*Fire Retardant Studies
Physics and Dynamics	*Smoke Aerosols	*Room Fire Growth	—	*Room Fire Growth	—	*Room Fire Growth
Toxicology	*Analysis of Smokes	—	*Pathology	*Sub-Acute Toxicity *Pathology	*Sub-Acute Toxicity *Acute Toxicity *Pathology	*Sub-Acute Toxicity *Acute Toxicity *Pathology
Products	—	—	—	—	—	*Apparel Standards *Furnishings Standards
Furnishings	—	—	—	*Room Fire Hazards Definition	*Full-Scale Room Studies	—
Construction	*Smoke Movement in Rooms	*Fire Loads		*Fire Loads *Fire Growth *Fire Stops	—	*Fire Loads
Detection and Control	*Detection Standards	*New Sprinkler Standards *Corridor Systems	*New Detection Concepts	—	—	—
Design Concepts	—		*Design Guide for Engineers	*Design Guide for Architects	—	*Selection Standards for High- Risk Areas

TABLE 2 (Cont.)

Relationship Between Center Programs and Intervention Strategies

Ignition Control			Control of Fire Spread and Growth		
Material Selection	Controlling Design	Behavior	Material Selection	Passive Design Concepts	Active Design Concepts
•Library •Hazard Analysis of Materials	•Library •Hazard Analysis Under CPSA, Sec. 7	•Library	•Library •Hazard Analysis of Materials	•Library	•Library
•Fire-Retardant Studies •Flame Intermediates	---	---	•Fire-Retardant Studies •Flash-Fire Studies •Flame Intermediates	•Flash-Fire Studies	•Flame Chemistry
•Ignition Studies •Smoldering Mechanism	•Ignition Studies	---	•Smoldering Mechanisms	•Room Fire Growth •Corridor Fire Studies	•Room Fire Growth •Corridor Fire Studies
•Acute Toxicity Standards	---	---	•Toxicity Standards for Materials	•Acute Toxicity •Sub-Acute Toxicity	•Smoke Particulate Studies
•Apparel Standards •Furnishings Standards	•Apparel Standards •Furnishings Standards	---	•Apparal Standards	---	---
•Furnishings Standards	---	---	•Full-Scale Room Burn Studies •New Small-Scale Tests	•Room Fire Hazard Definition	---
---	---	•Fire Load Studies	•Fire Growth Model •Fire Loads	•Fire Growth Model •Mobile Home Studies •Fire Stops	•Fire Growth Model
---	---	---	---	•Smoke Movement in Buildings	•Smoke Movement in Buildings
---	---	---	•Residential Guidelines	•Design Guide for Architects	•Design Guide for Engineers

room or corridor by experimental and mathematical analysis. This work forms the basis for predicting fire behavior and for controlling it by careful material selection and room design. Two other phases of the burning process, ignition and smoldering, are also being analyzed. Finally, a project is under way to sufficiently characterize smoke aerosol so that new potential routes of smoke detection can be identified.

Toxicology

One of the most direct ways of reducing fire losses is to understand and mitigate the toxic effects of fire gases. Work is being carried out in three different areas: lethal toxicity studies of materials; sub-lethal effects of toxicants, especially as they affect the ability to escape from fire; and detailed pathology of fire death. Results of these studies will eventually form the basis for guidelines for material selection by architects, engineers, designers, and homeowners. The immediate aim, however, is a preliminary test protocol that can be used to identify particularly hazardous materials at an early stage in product development, prior to widespread use in the marketplace. An extension of this work to a series of toxicity test methods will follow.

Consumer Products

Present codes and regulations do not cover most furnishings or general wearing apparel — items that figure very heavily in the current patterns of fire loss. Based on hazard analysis of the available data and information, this program is developing test methods that reflect the real fire situation. A cigarette ignition test for upholstered furniture and a classification test for upholstery fabric have been developed and submitted to CPSC. A draft general apparel standard has been submitted to CPSC (early in 1976). The program conducts various other studies, including the effects of dry-cleaning and laundering on garment flammability. It is developing (for CPSC) tests for products and materials covered by the Hazardous Substances Act to reduce the number, frequency, and severity of burn accidents.

Furnishings

This program is developing test methods to measure the hazard of interior furnishings. Full-scale burns of interior furnishings are conducted to study the hazard of individual pieces of furniture and the contribution of each piece to a developing fire. The rate of heat release, total energy output, and smoke production are measured in full-scale tests so that the validity of existing small-scale tests can be determined. The full-scale test data are also used in developing improved reduced-scale test methods. Development is under way of tests to measure rate of burning, surface flame spread, and ease of ignition of furnishing materials. These tests are central to characterizing, and eventually controlling, the hazards of these materials.

Construction

This program studies the fire performance of construction materials, develops test methods for building components, and develops models for predicting the course of fire in buildings, including conventional residences and mobile homes. A principal effort is the connection of test results such as rate of heat relese and flame spread with flashover in a room. This work is now to the point where flashover time can be estimated fairly well for various kinds of interior finishes in otherwise empty rooms. The program is working on the refinement of the fire load-fire severity concept and plans to develop improved techniques in fire endurance testing.

Detection and Control

This program develops design and performance criteria for automatic detection and suppression systems. Work has recently been completed on the first of a new generation of residential smoke detector standards. Extension of this technology, coupled with recommendations on the preferred siting of detectors in residences, is expected to accelerate the already vigorous pace at which residential smoke detectors are being accepted. Promoting this acceptance is a prime concern of the National Fire Prevention and Control Administration, and NBS works closely with the Administration in support of this goal.

The other principal program thrust is to develop more flexible standards for sprinkler systems, based on a sound knowledge of the technical requirements of fire suppression. Present standards are based on high-hazard experience and make little allowance for new concepts that could be applied to many light-hazard occupancies at greatly reduced cost. The NBS program in this area will be jointly conducted with the Fire Administration and will lead to the publication of engineering and design criteria for suppression systems.

Design Concepts

The data obtained in all the programs at the Center must be integrated into existing codes and will involve refinement of an integrated concept of safety versus risk for all structures. Existing codes do not always take into account projected new materials and configurations. What is needed is an organized body of technical data that will permit architects to use a rational approach to designing fire safety into buildings. This work draws on the expertise of a variety of NBS and outside experts. There are and will be significant contributions from the Center for Building Technology in projects ranging from surveying techniques for defining fire loads in buildings and thermal stresses in concrete beams to basic architectural considerations. Output is expected to take the form of design guides for architects and engineers; handbooks for the staffs of high-risk occupancies, such as hospitals; and guidelines for residential fire safety design. Therefore, a cooperative effort with the educational components of NFPCA is planned to disseminate new design concepts.

FIRE PROBLEMS

W. G. Berl
R. M. Fristrom
B. M. Halpin

Applied Physics Laboratory
The Johns Hopkins University
Laurel, Maryland

INTRODUCTION

Unwanted fires — small or large, trivial or destructive — are basically combustion processes controlled by the laws of physics and chemistry. Their qualitative behavior and quantitative description should be amenable to analysis and prediction. For example, suppose that the composition and placement of potentially burnable materials and furnishings in a room were known, as well as the nature of the ignition source and other relevant variables, such as the size and location of windows and doors. Should a fire start, one should be able to estimate how long it would be before the room or the structure containing it became unsafe or what measures would be required to stop it. Unfortunately, since the number of variables is so very large, one can, at best, furnish only rough answers in a few simple cases. Yet, in a narrow sense, the onset and the course of fires should be predictable. This, in turn, should provide guidelines for their prevention and control.

But an appreciation of their full social implications, particularly in urban settings, requires a broader outlook. It includes insights into the consequences of fires. What are the losses and why do they occur? It covers the techniques and tactics fashioned by the fire services to minimize damage. How well are countermeasures developed and how effectively are they applied? It deals with the training and equipping of hundreds of thousands of people who are needed to prevent or to extinguish fires. It involves the design skills of architects and products developers so that fires are avoided altogether or, at least, minimized when they occur. Not least, it requires an understanding of the behavior of people, as both the causes and the victims of fires, and of their actions and responses under stress. All these factors and more, make up the intricate matrix of the fire field.

It may come as a surprise that only quite recently a federally funded research effort has been mounted to unravel this complex skein. Its size is modest when measured against the substantial annual losses from fires in terms of the number of people killed, seriously injured, or incapacitated and of valuable goods destroyed or damaged. Its budget is much less than 1% of the expenses spent by communities

on protective forces that can be called on to prevent or suppress unwanted fires. Since 1970, the National Science Foundation, as part of its RANN (Research Applied to National Needs) program, has supported a number of centers throughout the United States in various aspects of fire research. The Applied Physics Laboratory was among the first grant recipients and has received substantial backing from this source ever since.

Recently, as the result of the National Fire Prevention and Control Act of 1974, the support function of this urban-oriented and people-directed research program was transferred to a new agency within the Department of Commerce. The National Fire Prevention and Control Administration (NFPCA), together with an expanded Fire Research Center at the U.S. National Bureau of Standards (NBS), has been given the responsibilities formerly carried by the National Science Foundation.

How many and what kinds of fires occur? What are the causes? Who is involved? Where are the hazards? How very little reliable information is at hand was shown by a recent National Household Fire Survey conducted by the U.S. Census and involving 0.05% of all U.S. households. It indicated that one in every ten respondents had experienced a fire incident, but that fewer than one fire in 10 involved fire department help. Both results were unexpected. The very large number of fires (roughly estimated as more than 5,000,000 each year), their widespread occurrence, the numerous variations in causes, the difficulty of reconstructing the crucial events of initiation, propagation, and extinguishment, the contributions made by maladjusted people who, through arson and false alarms, nearly double the fire losses and fire departmental workloads — all conspire to make it difficult to achieve a reliable evaluation of the magnitude of the problem on a national scale. Comparison of results among different cities or regions is hampered by difficulty in acquiring data. Only in a few special areas (such as the number of fatalities that resulted as direct consequence of a fire or the per capita investment of a municipality in fire suppression activities) is it possible to draw valid comparisons.

Although there are large uncertainties in the statistical data, the human loss appears to have stabilized in the neighborhood of 10,000 to 12,000 yearly deaths in the United States with perhaps two or three times as many injuries that require extensive hospitalization and involve expensive, traumatic recoveries. The direct economic losses are estimated at $2 to 4 billion/year, with two or three times as much outlay on prevention forces, insurance charges, code compliance, and other indirect costs. Despite substantial investment in fire-fighting forces, the U.S. fire loss record rates high in comparison with other countries in terms of per capita fire fatalities or other measurable criteria (Table 1). It is not clear whether this unhappy record is the result of a more thorough data collection system, an inordinately large number of potential ignition sources and fuel supplies, or inadequate public understanding of the elements of fire prevention.

From a multitude of choices, the research effort at the Applied Physics Laboratory covers four specific areas in which substantial contributions could be made, both to fundamental understanding of fire behavior and to practical implementations that would reduce fire losses. The four areas of primary interest are:

TABLE 1

Fire Losses for U.S., United Kingdom, and USSR

	U.S.	United Kingdom	USSR
Fires Responded to by Fire Service (per 1000 population)	4.5	3.1	0.16
Property Losses (per 1000 population)	\$20,000	\$2,500	\$125
Life Losses (per million population)	50	12.6	1.2

1. Fire Casualty Studies
2. Combustion Research
3. Systems Analysis and Development
4. Information and Education

In order to carry out these tasks, a number of collaborative efforts (primarily with the School of Hygiene and Public Health of The Johns Hopkins University, SHPH/JHU, and with fire and health agencies in the State of Maryland) were instituted. Close working relationships with organizations charged with the day-by-day tasks of public fire protection make it possible to relate the APL program to realistic conditions. It permits a rapid transfer of new insights and devices into the fire service, testing their value and effectiveness on the fire scene, and speeding up their adoption.

Work accomplished in the four areas of interest listed above is discussed in detail in the following sections.

FIRE CASUALTY STUDIES

Each year an unnecessarily large number of people either die in fires or are severely injured by them. The development of effective countermeasures to reduce these tragic losses requires an understanding of the physical and medical causes of fire fatalities and insights into who is involved.

INTRODUCTION

To most people becoming a fire casualty (injury or fatality) appears a very

simple process. Flames are hot and on exposure to them one gets burned. Smoke is generated in a fire and people are overcome by "smoke inhalation."

But this does not tell us for certain how or why people are dying and what protection should be made available to reduce these tragedies. Most people die as a result of a fire situation in which the flames have not reached them to produce burns. What are the causes of fire death? How do factors such as flame and smoke enter into the problem quantitatively? How important are alcohol, drugs, special materials, etc.? Do victims receive a warning? If victims receive a warning, why don't they or can't they escape? If time is a major factor, how much time do they need, and how can this time be provided?

To understand the mechanisms involved in becoming a fire statistic, one must recognize the complexity of the problem. An ignition source must be present which causes something to ignite. As a function of the environment and fuel load, fires will grow in many different ways. Depending upon the burning conditions, various materials will produce smoke laden with toxic gases, the most prevalent of which is carbon monoxide. Under these conditions the victim must react quickly and accurately to avoid becoming a fire casualty.

For this discussion we define three categories of fire casualties:

1. Due to burn
2. Due to "smoke inhalation"
3. Due to other causes

The first category refers primarily to thermal burns. The second category includes those people who have primarily suffered an insult to the respiratory system by the products of combustion, including chemical burns if they can be directly attributable to a fire. The "other causes" category includes such accidents as injury by falling objects, stepping on nails, falling down stairs, heart attacks, and other such events. There can be combinations of categories as well.

The APL/JHU program has placed primary emphasis on the "smoke inhalation" casualty problem since this area historically has had the least attention from the fire community and because most fatalities are now known to result from smoke inhalation. Burns, fractures, and heart attacks have been studied in great detail for a long period of time, and they continue to receive careful study.

"Smoke," as commonly used in fire terminology, is made up of gaseous and particulate matter. The materials in the smoke can be classified as:

1. Irritants (such as hydrochloric acid) which cause inflammation of the respiratory tract.
2. Asphyxiants, either lack of oxygen or agents which prevent oxygen from being used by (hydrogen cyanide) or carried to (carbon monoxide) the body tissues.
3. Drug-like materials which are absorbed by the blood, acting as anesthetics or otherwise affecting the central nervous system.

TOXIC ATMOSPHERES IN FIRES

Is there any need to be concerned about anything but the production of carbon monoxide and depletion of oxygen during a fire? An unequivocal Yes or No cannot be given. As will be shown, carbon monoxide is a contributor in most fire fatalities. Many different toxic materials can be present during a fire, and their presence and quantity depend upon many factors such as composition of the material burning, temperature, amount of oxygen available, and other parameters such that, as a result, it is difficult to define the toxic atmosphere of any one fire and its possible effect.

In numerous laboratory studies, the thermal decomposition of household materials has been examined for toxic materials. Tables 2 and 3 indicate some of the gases and organic materials that have been identified when household items burn.[1,2]

Most of the substances shown in Tables 2 and 3 are toxic if there is exposure to a large enough concentration for sufficient time. Table 4 shows average tolerable human exposure limits for some gases.[3]

Figure 1 indicates the rate of uptake of CO by a human measured as the blood carboxyhemoglobin level in percent.[4] The data are for different concentrations of CO.

TABLE 2

Toxic Products That May Be Obtained from Combustible Materials (Reference 1)

Toxic Gas or Vapor	Source Materials
Carbon dioxide & carbon monoxide	All combustible materials containing carbon
Nitrogen oxide	Celluloid, polyurethanes
Hydrogen cyanide	Wool, silk, plastics, containing nitrogen
Formic acid & acetic acid	Cellulosic materials, cellulosic plastics, rayon
Acrolein	Wood, paper
Sulphur dioxide	Rubber, thiokols
Halogen acids	Polyvinyl chloride, fire-retardant plastics, fluorinated plastics
Ammonia	Melamine, nylon, urea formaldehyde resins
Aldehydes	Phenol formaldehyde, wood, nylon, polyester resins
Benzene	Polystyrene
Phenol	Phenol formaldehyde
Azo-bis-succino-nitrile	Foamed plastics

TABLE 3

Combustion Products of Plastics and Other Common Solids (Reference 2)
(grams/gram of sample)

	Poly-Styrene	Ethyl Cellulose	"Saran"	PVC	Nylon	Rayon	Wool	Silk	Wood	Paper
Condition No. 1 — Free burning										
Carbon dioxide	2.192	2.294	1.047	0.433	1.226	1.836	1.541	1.352	1.626	1.202
Carbon monoxide	0.174	0.440	0.022	0.229	0.304	0.116	0.446	0.634	0.270	0.135
Aldehyde*	—	—	—	—	0.0064	—	—	0.0024	Trace	—
Phosgene	—	—	—	0.0001	—	—	—	—	—	—
HCN and RCN	—	—	—	—	0.0076	—	0.007	0.036	—	—
Ammonia	—	—	—	—	0.032	—	—	0.053	—	—
Chlorine-HCl	—	—	0.621	0.496	—	—	Trace	—	—	—
Acidity†	—	—	—	—	—	—	—	—	—	0.0009
Condition No. 2 — Smoldering										
Carbon dioxide	1.698	0.202	0.416	0.743	0.907	1.130	0.650	1.033	0.934	1.001
Carbon monoxide	0.540	0.172	0.221	0.086	0.355	0.225	0.138	0.141	0.366	0.273
Aldehyde*	0.003	0.012	—	—	0.0065	—	‡	0.0012	Trace	Trace
Phosgene	—	—	—	0.00008	—	—	—	—	—	—
HCN and RCN	—	—	—	—	0.0098	—	0.008	0.007	§	—
Ammonia	—	—	—	—	0.210	—	0.035	0.308	—	—
Chlorine-HCl	—	—	0.774	0.473	—	—	Trace	—	Trace	—
Acidity†	—	—	—	—	—	0.042	—	—	0.009	—

* As formaldehyde.
† As acetic acid.
‡ Positive, but interference.
§ Interference.

TABLE 4

Maximum Concentration (PPM) of Gas in Air Which is Tolerable by Humans Exposed for the Specified Time (Reference 3)

Gas	Concentration	Time (Min.)
Carbon monoxide	1000	60
Hydrogen chloride	50–100	60
Hydrogen cyanide	200–480	30

Henderson, Y., and Haggard, H. W., ACS Monograph Series, *Noxious Gases,* 35, Reinhold Publishing Corp., New York, 1943.

EXPOSURE PROBLEMS

There is some controversy regarding the tolerance level for carbon monoxide. For a person in good health the lethal level of blood carboxyhemoglobin (i.e., the fraction of hemoglobin occupied by carbon monoxide rather than oxygen) ranges from 50 to 65%. It is now believed that as little as 20% blood carboxyhemoglobin in conjunction with pre-existing heart disease or high levels of alcohol or drugs can also be lethal. While the 50 to 65% threshold values are reasonably well agreed to, there are as yet very little data to substantiate the second claim. The APL program is attempting to define limits in this area.

There is even more uncertainty among fire researchers, toxicologists, and physiologists on whether the consequences of the toxic gases or materials are additive or synergistic in nature and what effect the ingestion of sublethal concentrations of several toxic gases will have. Animal studies to date have not been fully conclusive, especially if the toxic substances represent the three major categories defined above. Also the problem of extrapolating animal results to humans remains. Whatever the answers, a person is exposed to a very dangerous atmosphere during a fire.

"OVERCOME" CASUALTIES

The "overcome" casualties of fire receive treatment at the scene or must be transported to hospitals for further treatment. They may or may not recover. Smoke inhalation can be serious or fatal in a short time. Many fatalities are at the fire scene where exposure to toxic gases may have been measured in minutes. If they survive for a short time and then die, they have usually developed respiratory difficulties, such as edema, inhibiting effective transfer of oxygen to the blood. This is in contrast to asphyxiants that interfere with the supply of oxygen to the body tissue. Burns are relatively rare as cause of death, but can easily mask the asphyxiating causes in the absence of detailed investigations.

The major chemical asphyxiants which can contribute to the "overcome" problem are carbon monoxide and hydrogen cyanide. Detection of hydrogen cyanide involvement is elusive. Hydrogen cyanide has been detected as a pyrolysis product of nitrogen-containing substances (such as wool, nylon, and polyure-

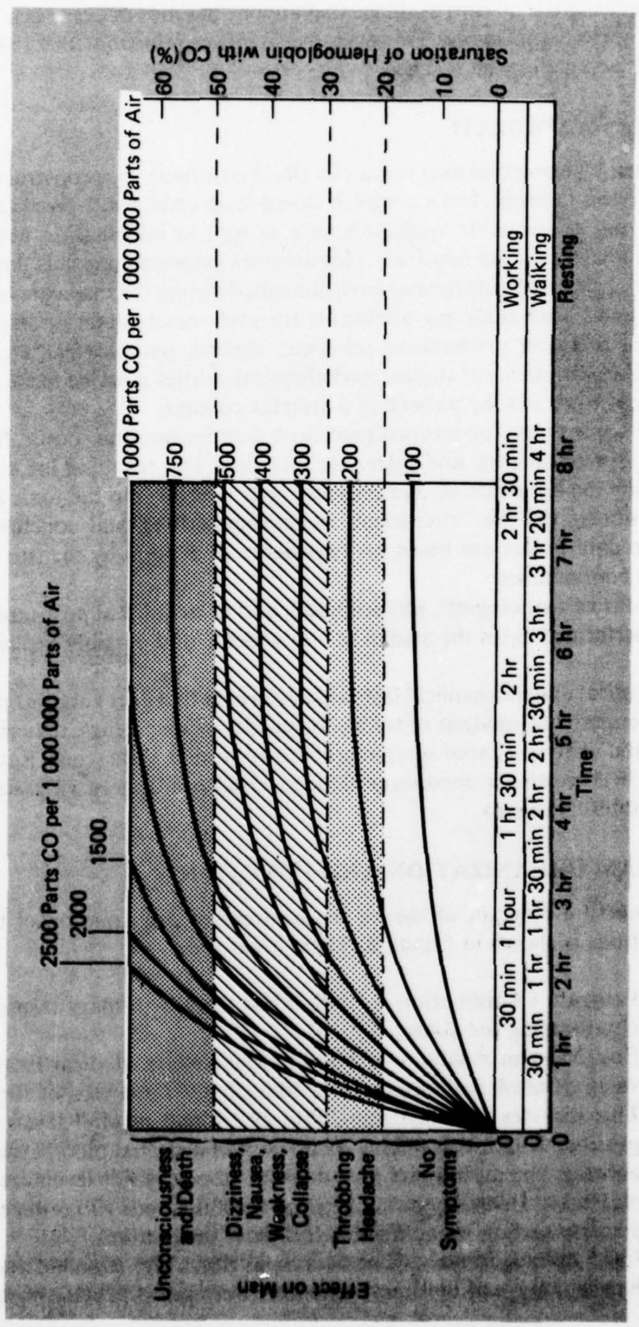

FIGURE 1 Effects on man of various concentrations of carbon monoxide (Ref. 4).

thane), but there is no firm evidence that anyone has died or even been hospitalized because of cyanic poisoning. However, recent information indicates that dangerous levels of cyanide can be reached.

SYSTEMS APPROACH

When a person dies as a result of a fire it is difficult to reconstruct causes and consequences in detail. It is a complex closed-loop system with feedback. Analysis requires use of available applicable data as well as information obtained from in-depth analysis of fire fatalities. This involves gathering physical data about the fire, attempting to define the fire environment, defining the medical consequences, and reviewing and analyzing applicable research results in an attempt to understand the pertinent mechanisms (physical, clinical, pathological, etc.). Detailed case studies, biochemical studies, and chemical studies must be made. Figure 2 is an attempt to depict the pattern in a systems context.

The scene of the fire is investigated to determine ignition source, first items of ignition, spread factors, and materials involved. The resulting information aids in defining the fire situation and provides some insight into the toxic atmosphere present during the fire. Interpretations, extrapolations, and conclusions drawn from the data points are based on experience or reports by the fire service and research communities.

Extensive pathological, physiological, and toxicological post-mortem analyses are performed to fix the medical cause of death and possibly explain failure to escape.

Chemical and biochemical tests are performed to detect volatile organic gases by lung outgassing, analysis of tracheobronchial tree scrapings, materials identification, and analysis of soot scrapings obtained from the fire scene. Resultant data are used to correlate the conditions in the external atmosphere with analysis of the victim's internal organs.

PROGRAM ORGANIZATION AND FUNCTIONS

A function diagram of the six major areas of participation of the various organizations is shown in Figure 3. These areas are:

1. Program Coordination — APL/JHU has the primary responsibility of coordinating the study.
2. Post-Mortem Analyses — The Maryland State Medical Examiner provides detailed pathological and toxicological analyses of fire fatalities. This includes carboxyhemoglobin and blood alcohol levels as well as possible drug involvement. As a result of a special blood cyanide study, accurate and meaningful post-mortem blood cyanide levels are now being measured. Heart condition is given careful scrutiny in order to evaluate possible carbon monoxide-heart disease interactions.
3. Field Investigations — The Maryland State Fire Marshal and his staff, local county, and Baltimore City fire investigators provide routine reports

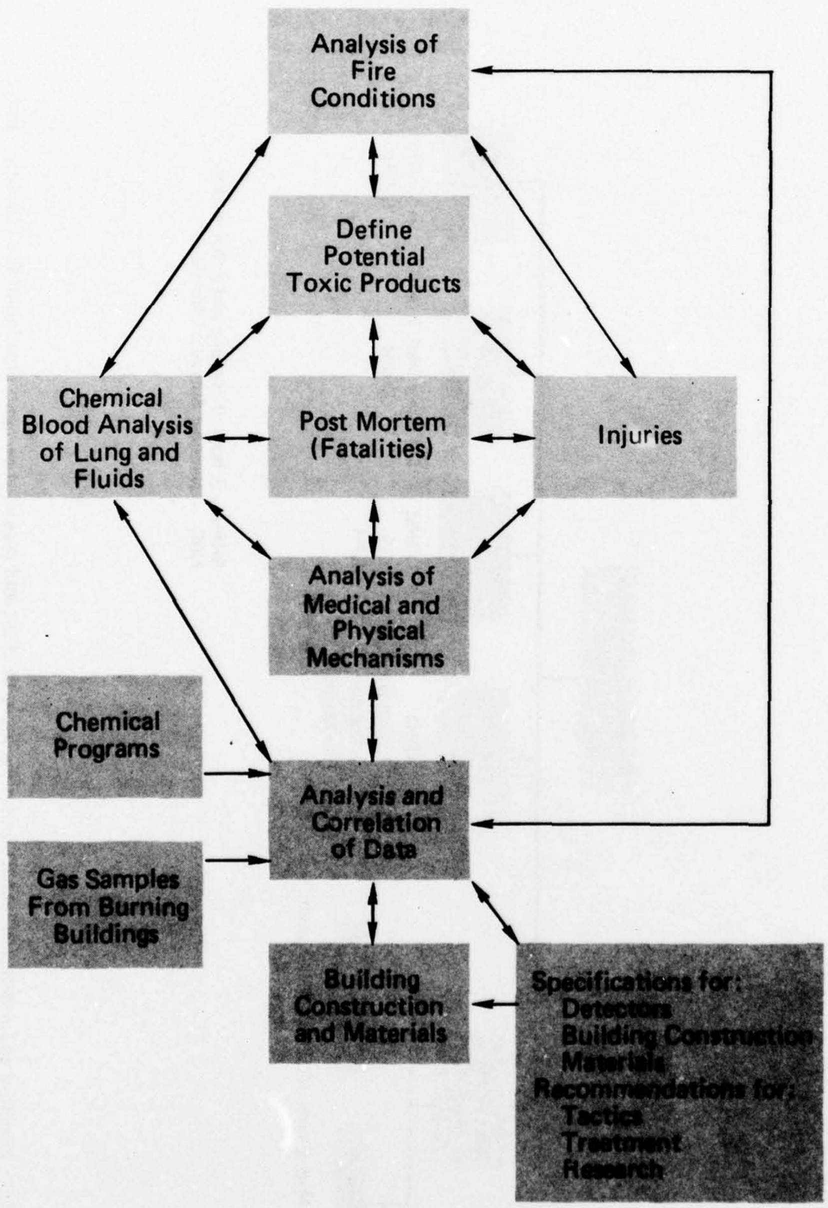

FIGURE 2 Systems approach to fire casualties problem as a closed-loop system with feedback.

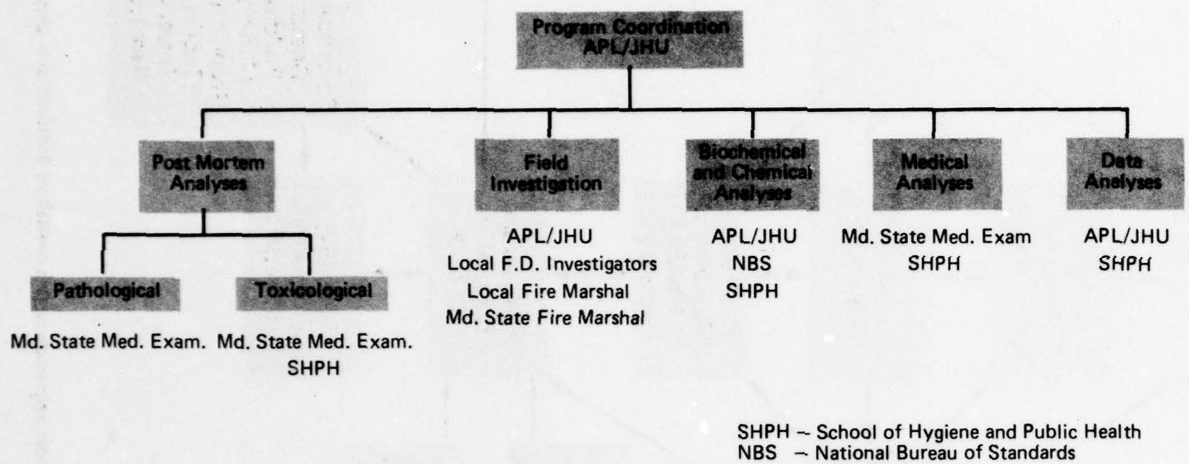

FIGURE 3 Function and organization chart indicating areas of effort and organizations participating in fire casualties study.

on physical aspects of the fires and the demographic information about the victims. An APL fire investigator visits the scene in an attempt to obtain samples of materials that were involved in the fire, soot samples, and the data provided by the fire department investigators.

4. Biochemical and Chemical Analyses — Analyses are made by APL and the National Bureau of Standards on biological and other samples obtained during the autopsy and at the fire scene. Lung tissue for outgassing, tracheobronchial tree scrapings for metal analysis, fire-involved materials, and soot are analyzed.
5. Medical Analyses — When the post-mortem and biochemical data are available, a medical group analyzes them. A judgment is made about the cause of death and, if possible, a reason is given why escape did not take place. The Medical Examiner and School of Hygiene and Public Health provide these functions.
6. Data Analyses — All data for each case are analyzed to correlate the physical, medical, and other findings. At this time, conclusions about fire fatalities can be drawn that may aid in understanding the conditions and allow suggestions of practical solutions. The entire group is responsible in this area with most of the effort centered at APL.

SAMPLE POPULATION

The fatality program was designed to include primarily "overcome" cases in the State of Maryland that did not involve extended hospitalization. Maryland State Law requires an autopsy on all victims of violent death (which includes fire). However, medical examiners have the authority to waive an autopsy if, in their opinion, the cause of death is "obvious." In the early stages of the study, in particular, some of the fire fatalities were not autopsied and could not be included in the overall analysis. Persons who die in explosions or in automobile accidents with attendant fires are included in the data base if fire was the primary cause of death.

CASE DATA AND RESULTS

From September 1971 through December of 1974 there were 206 fire fatalities that met the time and autopsy criteria of the study, i.e., the victim must have died within six hours of the fire incident and an autopsy must have been performed. This represented approximately 50% of the fire fatalities that occurred in the State of Maryland during the study period. Approximately 45% occurred in the City of Baltimore, where all fire fatalities of interest were autopsied. Since between 25 and 30% of the fire fatalities in the State of Maryland occur in Baltimore, the overall results are somewhat biased toward Baltimore.

Approximately 140 fatalities were not submitted by the loal authorities for detailed autopsies so were not included; there is no reason to believe that the omission affects the conclusions of the study. However, the seventy fatalities (20% of the total) that occurred six hours or more after rescue had quite different case histories.

The 206 fatalities occurred in 172 fires throughout the State of Maryland. There were 157 fires in residences (e.g., house, apartment, mobile home, etc.). Fifteen others occurred outdoors or in an auto or other vehicle. There were no fatalities in industrial or manufacturing fires, nor were there any airplane fire deaths.

Sixty-two people died in 29 of the fires; i.e., 30% of the victims died in 17% of the fires. Not all of these victims are included in the study since autopsies were not performed on all of them. In the reported data there were no more than four fatalities in any single incident. (However, it should be noted that in several more recent fires, seven or eight persons have died in the same fire.)

The suspected causes of the fatal fires in this study are given in Table 5. "Smoking" covers misplaced cigarettes, cigarettes discarded in wastebaskets, etc. This is by far the greatest contributor to fatal fires in Maryland. Fifty-two percent of the fires are traceable to "smoking," the remainder being due to a large variety of causes.

Human error is a key problem as may be seen by Table 5. Smoking and careless use of matches and candles together account for 61% of the fatal fires. Many of the flammable liquid fires can be attributed to mishandling and storage, and some of the fires classified as "other" are caused by lack of proper precaution.

The causes of fires in Table 5 differ significantly from fires which result primarily in damage to property. Malfunction of heating and electrical equipment and kitchen-originated fires are found to be the predominant cause of property damage.

Fires caused by "smoking" also require attention to the involvement of alcohol, a factor in 70% of the "smoking" fires. More than one-third of the fires are due to the combination of alcohol use and smoking.

Alcohol must be considered a serious problem in the ignition, detection, and

TABLE 5
Cause of Fatal Fires as Indicated by Fire Investigators for the Time Period September 1971—December 1974 (172 Fires)

"Smoking"	52%
Careless use of matches	7
Flammable liquids	8
Heating equipment	6
Electrical malfunctions	4
Careless use of candles	2
Other	11
Unknown	10
	100%

escape phases. The data indicate that men in the "40 and over" age bracket are heavy contributors to fires in which smoking and alcohol are both involved.

Figure 4 shows the age distribution and alcohol involvement of fire victims. These data are absolute values and are not normalized to population data. Note that young children and adults over 60 are more frequent fire fatalities than people in other age brackets. Several reasons are suggested. The very young have not physiologically matured to withstand the toxic fire atmosphere, and older people succumb to the toxic stresses. The young are unable to escape on their own and are frequently lost in fires.

Since smoking-related fires are most frequent, it is not surprising that most fatal fires originate in the bedroom and living room. Fires originated in the bedroom in 49% and in the living room in 22% of the incidents (see Table 6). The listing of room origin as shown in this table differs significantly from estimates of the most frequent point of origin of all fires, which is the kitchen. This difference must be considered in the design of countermeasures for reducing fatal fire losses.

The location of the victim is shown in Table 7. Forty percent of the victims were found in the room of origin of the fire.

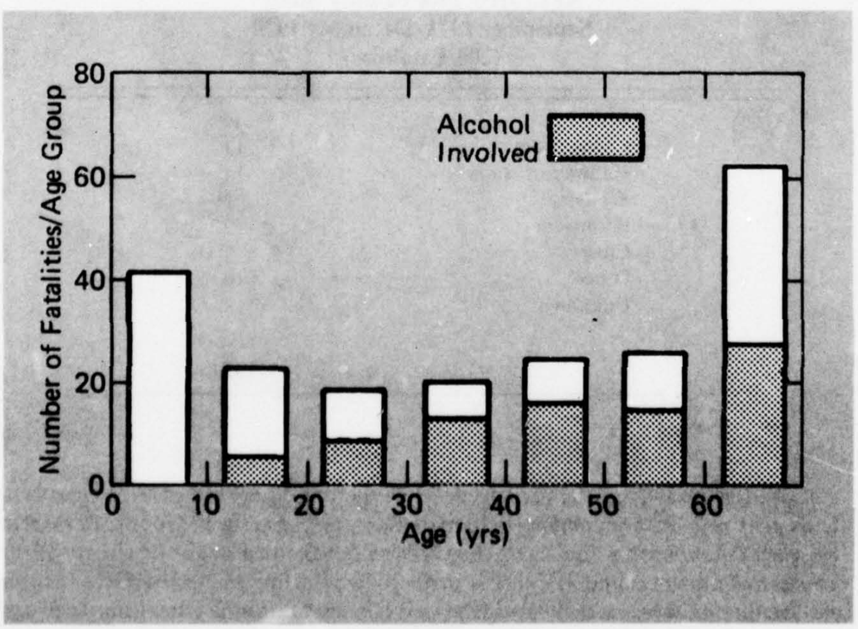

FIGURE 4 Age distribution and alcohol involvement in the fire fatalities included in the APL/JHU study for the period Sept. 1971—Dec. 1974.

TABLE 6

Room of Origin
APL/JHU Fire Fatality Study
September 1971–December 1974
(172 Fires)

Bedroom	49%
Living room	22
Kitchen	7
Basement	6
Dining room	1
Other	12
Unknown	3
	100%

TABLE 7

Victim Location
APL/JHU Fire Fatality Study
September 1971–December 1974
(206 Fatalities)

Bedroom	49%
Living room	17
Hallway or stairs	14
Kitchen	2
Bathroom	2
Closet	3
Other	10
Unknown	3
	100%

A large number of the fires occur while the victims are in bed. Another problem exists with children playing with matches — hiding in the bedroom offers them privacy. Often when a fire starts they hide under the bed or in the closets of the rooms and are not found in frantic searches when the fire is detected. Other people fall victims in the bedroom because they have entered that area attempting to rescue others or to save valuables. Others appear to be using the bedroom as an escape route. Thus, the very privacy of the bedroom area appears to contribute to the danger.

Victim location shows that about 80% of all victims physically able to escape

were alerted and attempted to escape. In some cases they had sufficient time to give an alarm to others or to notify the fire department, but delayed escape. It is clear that there is an insufficient understanding of the several dangers presented by fire. Erroneous decisions are frequently made. People use precious time attempting to extinguish the fire and in some cases do not alert others.

The question of time requires discussion. Very little reliable information is available concerning the lapse of time between ignition and alert for need to escape from the hostile environment. Some attempted escapes fail because of panic or improper moves, but most victims appear to have enough warning to escape. In some cases (smoldering types of fires), hours are available to detect the problem, sound an appropriate alarm, and escape. When information about the "smoking" type fire is sought, people often remember having handled or having seen cigarettes handled approximately two to three hours prior to the detection of the fire. In other fires (flash fires) the time factor is in the order of minutes. The real time safety factors are not known.

Another point of interest is the time of day that the fatal fires occur. Many fire department personnel believe that *all* fatal fires occur between midnight and 4 a.m. There are peaks during this time period, but they account for only 31% of the fires. The time of day distribution in a study of the fire fatalities in Maryland during 1967–1968[5] showed similar results.

Fire fatalities increase during the colder months. This fact cannot be attributed completely to the use of heating equipment during that portion of the year. Table 5 showed that only a small fraction of fires resulted from faulty heating equipment. Closed buildings are poorly ventilated resulting in high concentrations of toxic products within.

The medical causes for fire fatalities are primarily based on measurement of the carboxyhemoglobin content (i.e., the amount of carbon monoxide attached to red blood cells). The distribution of blood carboxyhemoglobin (COHb) levels is shown in Figure 5. It is assumed that a 50% level is sufficient to be assigned as the cause of death. Thus, approximately 50% of the fatalities studied are classified as due to carbon monoxide poisoning. In 30% of the fatalities a combination of blood carboxyhemoglobin (between 20% and 49%) and other factors such as pre-existing heart disease, high levels of blood alcohol, or burns was blamed. These combinatory effects are being more carefully analyzed to determine the appropriateness of the conclusion.

The two groups, both involving carbon monoxide, account for 80% of the fatalities. In half of the remaining cases, which include self-immolation, victims have very low blood carboxyhemoglobin levels and usually insufficient skin surface burns to cause death. It has been concluded that laryngeal spasms occur which do not release until the victim is asphyxiated.

In the remaining 10% of the cases sufficient toxicological or pathological reasons for death cannot be found. The types of fire in these cases may indicate that some other as yet unknown toxic agents are responsible. These incidents are under special study.

Importantly in victims having a COHb level of 15% or more, significant soot

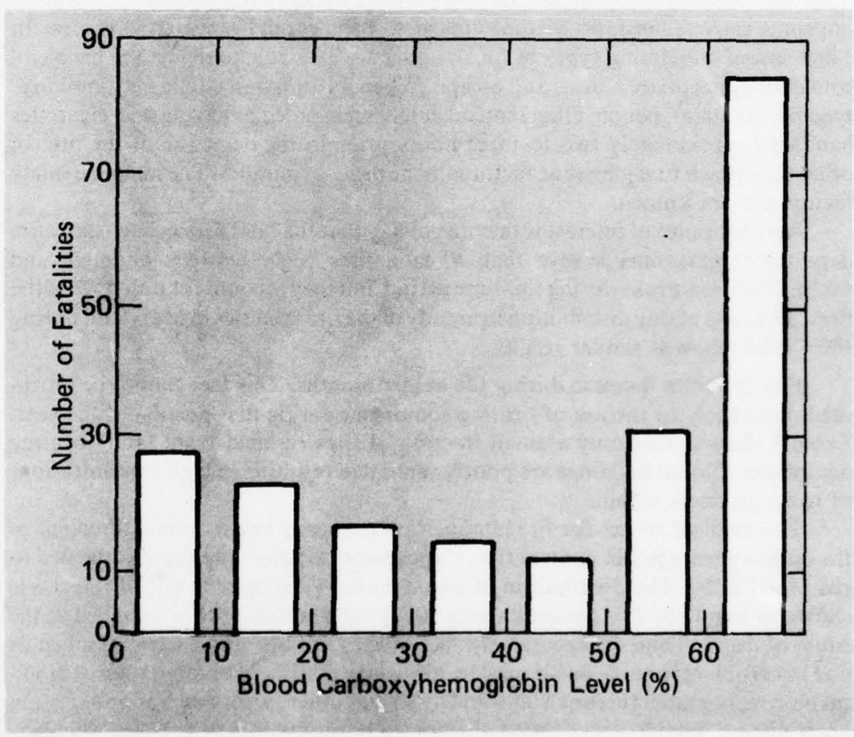

FIGURE 5 Distribution of blood carboxyhemoglobin levels included in the APL/JHU study for the period Sept. 1971—Dec. 1974.

deposition can be found in the lower respiratory system. The significance of this may be that soot is a vehicle for transporting toxic agents, such as HCl[6] and HCN and other substances such as metal oxides, that may cause toxic poisoning and/or edema leading to severe respiratory complications. One flash fire gave rise to rapid lung edema with heavy soot deposits, but a low COHb level.

While synthetic polymeric materials are frequently involved in fires and produce irritating or toxic gases such as HCl and HCN, they have been the primary articles burning in only 5% of the fires reported in this study. Thus, at this point we cannot state that smoke from burning synthetic materials is a significant factor in the fire deaths in Maryland.

HEART STUDY*

During pollution alerts, people with respiratory and heart problems are advised to avoid extended exposure to the outdoors. Atmospheres at a fire scene are highly polluted. It is not surprising, therefore, that persons with pre-existing heart and respiratory disease can be assumed to be in great jeopardy in a fire. As a result, it is likely that the deaths of some people can be ascribed to a combination of a sublethal level of carboxyhemoglobin and some degree of atherosclerosis and lung disease.

A special study of the coronary trees of fire victims was undertaken in an attempt to define the interactions between heart disease, carbon monoxide and its fatal consequences. No corresponding study of lung disease and carbon monoxide exists. The approach is to isolate the arterial tree from the heart of the victim (Figure 6), each branch to be sectioned and examined millimeter by millimeter. Figure 7 gives a view of the sections of a branch which indicates varying degrees of closure of the lumen.

It is currently believed that there is a relationship between the degree of closure, the distance of the blockage from the heart, the arterial branch in which the blockage is located and the CO level. This hypothesis has a scoring system for the severity of the coronary stenosis.

Since the results are probably influenced by parameters such as age, sex, race, heart condition, blood carboxyhemoglobin levels, medication, and other gases, it is quite difficult to isolate the appropriate parameters.

To establish to what extent age was a factor, Table 8 was obtained for 72 people who were victims of residential fires. It is interesting to note the incidence and degree of pre-existing heart disease in the 20–39 year age span, since this does not fit the pattern of heart disease in the normal population. It is plausible to conclude that in the Fatality Study there is a strong tie between heart disease and the fire deaths.

Figures 8 and 9 attempt to show the distribution of blood carboxyhemoglobin versus the coronary stenosis score (percentage of narrowing) for men and women. A coronary stenosis score of 30 has been selected as a critical point.

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*This study is under the direction of Dr. R. A. Fisher (State of Maryland Medical Examiner).

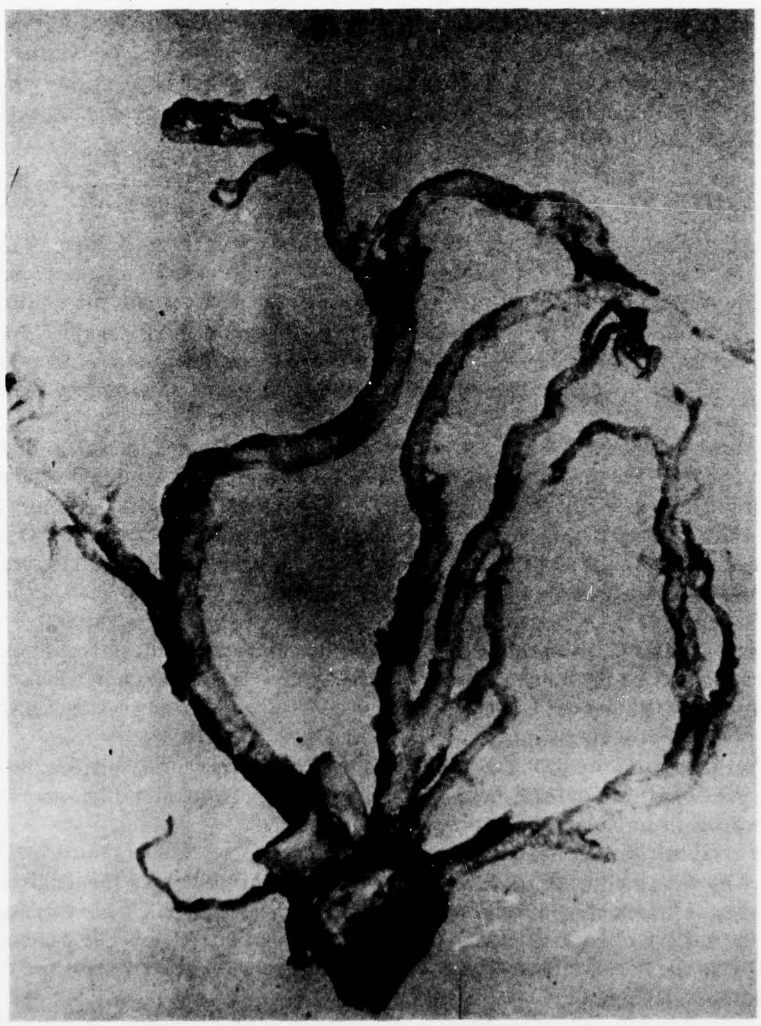


FIGURE 6 Arterial tree isolated from the heart.

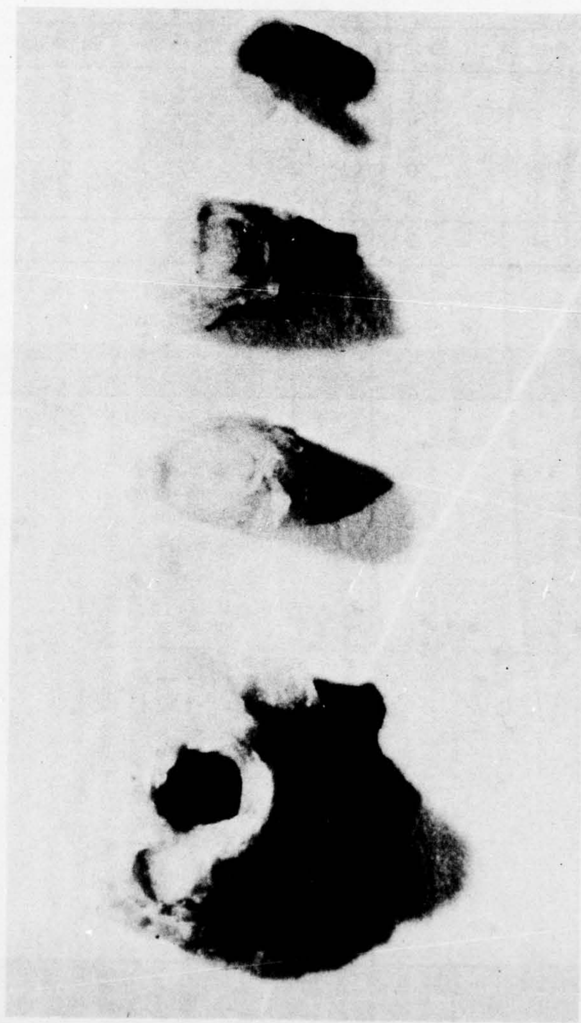


FIGURE 7 Sections of a branch of the arterial tree showing various degrees of closure.

TABLE 8
Percentage Coronary Arterial Narrowing in Fire Victims as a Function of the Age of the Victim

	Percentage Narrowing					
Age (Yrs)	0 to 24	25 to 49	50 to 74	75 to 89	90 to 100	Total
20 to 39	9	1	3	4	6	23
40 to 49	1	0	2	0	9	12
50 to 59	1	2	2	1	6	12
60 to 69	2	0	2	2	9	15
70 +	1	0	3	0	6	10
Total	14	3	12	7	36	72

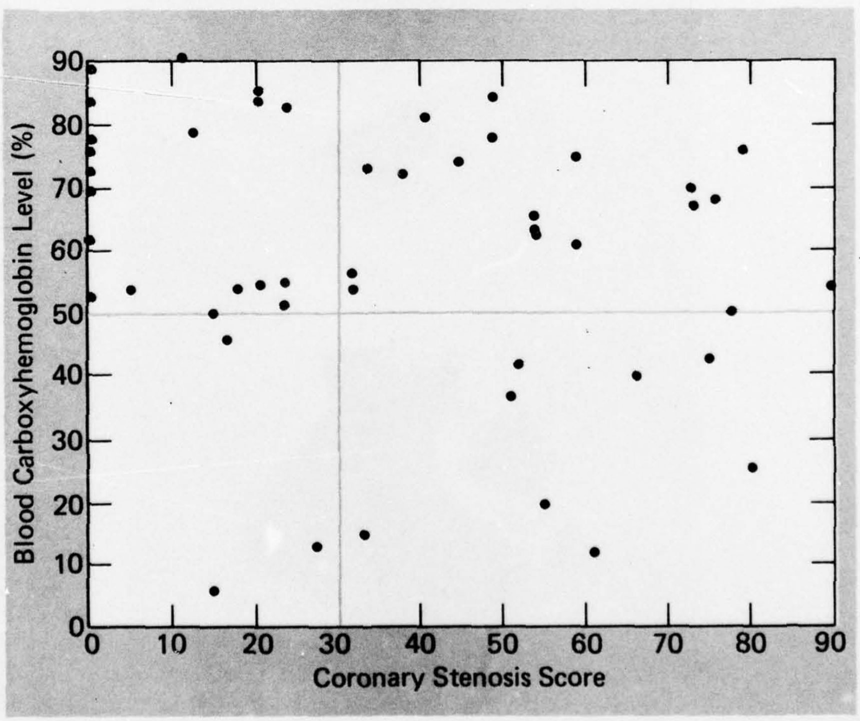


FIGURE 8 Carboxyhemoglobin level versus coronary stenosis (51 men).

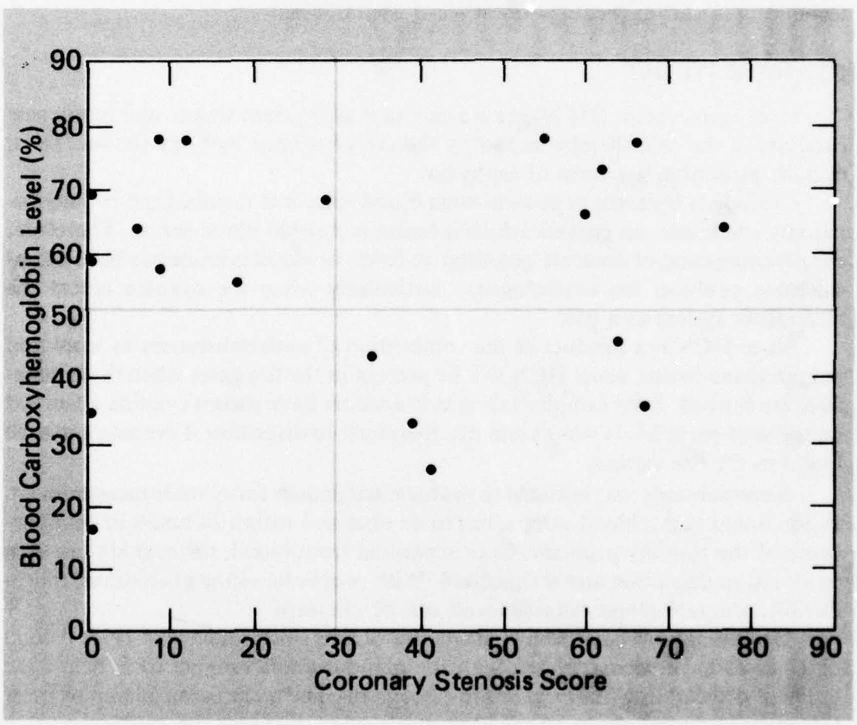


FIGURE 9 Carboxyhemoglobin level versus coronary stenosis (21 women).

If the hypothesis were true that people with pre-existing heart disease cannot tolerate as much carbon monoxide as those with unimpaired hearts (because of inability to compensate for the diminished oxygen delivery), then one would expect to see in Figures 8 and 9 a significant number of cases with a stenosis score of 30 or more with blood carboxyhemoglobin levels below 50%. The data in Figures 8 and 9 partially bear this out, but do not fully explain the sizable number of fatalities of people with severe heart disease (i.e., high stenosis score) who survived long enough to build up a carboxyhemoglobin level of about 50%.

CYANIDE STUDY*

Hydrogen cyanide (HCN) gas is a chemical asphyxiant which inhibits enzyme catalysts in the cell, thereby impairing the use of oxygen by body tissues. Thus, cyanide poisoning is a form of asphyxia.

Cyanide is unstable in post-mortem blood since it is metabolized to thiocyanate by rhodinase, an enzyme which is found in normal blood serum. Therefore, the determination of accurate quantitative levels of blood cyanide has been a considerable problem for toxicologists, particularly when the cyanide enters the respiratory system as a gas.

Since HCN is a product of the combustion of such substances as wool and polyurethane foams, some HCN will be present in the fire gases when these materials are burned. Soot samples taken at fire scenes have shown cyanide adsorbed on the soot particles. It was of interest, therefore, to determine if cyanide could be found in the fire victims.

A special study was initiated to evaluate techniques for cyanide measurement. It was found that a blood sample has to be obtained within 24 hours of death because of the stability problem. Once separated from blood, the cyanide can then be stored as a solution and refrigerated. With proper handling procedures, reproducible, accurate blood cyanide levels can be obtained.

Determinations have been made on fire victims since January of 1975. A total of 77 cases have been analyzed with the blood cyanide ranging from below the limits of detectability (0.01 μg/ml) to 4.36 μg/ml. The latter is considered by most toxicologists to be above lethal level and could, therefore, be considered as a primary cause of the fatal outcome.

With the growing capability of measuring levels of a variety of toxicants in addition to carbon monoxide, it becomes increasingly important to identify the materials burned in the fatal fires as well as other pertinent fire scene data such as body location. The presence of a significant blood cyanide level, together with a high cyanide level in the soot samples, as well as of materials which can produce cyanide during a fire would tend to substantiate claims that cyanide is present and responsible for incapacitating some of the fire victims. If found in a significant number of cases it would shed more light on the possible effect of a sublethal level in influencing behavior in ways which make escape from fires difficult or impossible.

*This study is being directed by Dr. Y. H. Caplan (Chief Toxicologist, State of Maryland Medical Examiner's Office).

ANALYSIS OF SOOTS AND ORGANIC VAPORS*

Controlled combustion in furnaces and engines, where excess air is available, rarely produces toxic or objectionable combustion products. However, in most fires, where there is not only generally a substantial deficiency of air and poor mixing of fuel and air but also frequently a substantial thermal breakdown of materials into substances that are not involved in the combustion reactions, the amount and variety of objectionable products can be very large indeed. Thus, the smoke and gases from fires play an important role, and in the case of fire fatalities, a dominant role. Their consequences are not confined to persons caught unawares in fire situations, but extend to the fire fighters who are required to do their suppression work inside gas-filled buildings.

The chemical complexity of the reaction products is enormous. It depends so much on the nature of the involved materials, their spatial arrangement, the level of radiation that leads to thermal breakdowns, oxygen concentration, and other variables that it is virtually impossible to make predictions about composition and quantity. However, from many model experiments and laboratory tests, a substantial body of empirical information has been accumulated that gives some guidance as to what can be expected. Thus, the almost universal presence of carbon monoxide, frequently in very high and toxic concentrations, is well established. If the fuel contains nitrogen (as is the case for wool, nylon, or polyurethane plastics), hydrogen cyanide is formed in substantial amounts. Polyvinyl chloride (PVC) is a copious source of hydrochloric acid on burning. Aldehydes, well known as irritants of eyes and mucous membranes, are common constituents of fire gases. In addition, complex liquid tarry materials, ill-defined solid soots or mixtures of the two are readily formed, particularly from synthetic polymers such as polystyrene or polyurethane.

In addition, in real-life situations where the fires are not confined to one substance alone, a number of additional combustion products may appear. When involved in fires that generate reducing atmospheres at high temperatures, metals, such as copper or cadmium from electrical appliances, inorganic substances, such as lead or titanium from paint pigments, or intended flame inhibitors containing bromine or antimony, can turn into gaseous products or become aerosols of small particle size which are carried with the other gaseous reaction products throughout the structure and into the lungs of occupants.

A program is under way to clarify the nature of the substances that are actually ingested by persons who have become fire casualties, apart from such gases as CO or HCN that are measured as part of the general autopsy. This is done by a detailed chemical and instrumental analysis of the "internal" soots that can be isolated from the tracheobronchial trees of fire victims and of "external" soot deposits that are collected at the fire scene from walls, mirrors, or windows. The former will not give evidence for compounds that are readily dissolved by body fluids (such as hydrochloric acid). The latter, on the other hand, presents a total cross-section of all the

*Dr. Geraldine A. Fristrom and D. O. Shapiro conducted the experiments and data analysis for this section.

particles that are deposited during the course of the fire, extending well beyond what may have been ingested by the fire victim. Nevertheless, a rough correspondence should exist between the two.

The results of this program indicate that sooty deposits are found in the trachea and bronchia of nearly all the fire casualties. Furthermore, the "external" and "internal" soots contain a surprisingly large number of inorganic metals, frequently in large amounts (Tables 9 and 10). The chemical nature of the metallic compounds in terms of composition or particle size is not yet known. Nor are the mechanisms clear by which they were transported from the source into the victims' lungs. It raises as yet unresolved questions concerning their clinical significance, particularly in those instances where fire exposure had led to serious injury rather than death. However, it has been noted that "internal" soots may contain very large amounts of adsorbed hydrochloric acid (10% by weight has occasionally been observed), presumably from chlorinated polymers, which can produce severe chemical burns in the lung tissue. Clearly, proper antidotes should be provided quickly if such large amounts of a corrosive acid have been ingested.

Detection of volatile organic substances has proved somewhat difficult. A number of substances like ethyl alcohol or acetone are frequently present, but cannot specifically be attributed to the fire gas atmospheres. However, a careful determination of gases released from outgassed lungs of fire victims made it possible to isolate acetaldehyde as a specific substance that must have had its origin in the fire combustion products.

The conclusion that has been reached thus far is that the "minor" toxic con-

TABLE 9

Fire Casualties
Tracheobronchial Tree Analyses
(Atomic Absorption)

	Metals (μg/g Sample)				
Sample	Cd	Cu	Mn	Pb	Sb
1	—	344	—	—	—
2	28	33	—	708	—
3	4	227	15	30	—
4	—	376	28	—	—
5	28	13	—	38	638
6	14	—	—	767	—
7	5	—	—	—	643
8	29	9	—	580	182
9	26	16	—	363	—
10	24	8	—	608	58
11	19	—	—	453	—

— indicates concentration was below the detection limit.

TABLE 10
Fire Casualties
External-Internal Correlations
(μg/g of Sample)

	Cd	Cu	Mn	Pb	Sb	Cl^-
Case 1						
Ext.	41	30	28	174	6847	101090
Int.	5	---	---	---	643	
Case 2						
Ext.	69	48	41	394	---	42450
Int.	87	45	---	150	---	
Case 3						
Ext.	707	64	40	7045	1102	21420
Int. 1	29	9	---	580	182	
2	26	16	---	363	---	
3	24	8	---	608	58	
4	19	---	---	453	---	
Case 4						
Ext.	55	20	---	1855	---	
Int. 1	2	11	1	11	---	
2	17	16	---	40	---	
3	20	14	---	44	---	
4	23	9	---	37	---	

--- indicates concentration was below the detection limit.

stituents that are found in or suspected to have entered the lungs of fire victims can rarely be held responsible for fire fatalities that occur quickly. However, in delayed cases, where the effects of carbon monoxide (or, possibly, of hydrogen cyanide) were not fatal by themselves, the subsequent medical consequences may be strongly affected by the nature of the "minor" products. Aldehyde irritations, acid burns, and metal toxicity are all potential contributing factors in varying degrees. Their nature and severity could be ascertained, and proper countermeasures taken, if "external" soot analyses were carried out routinely or if "internal" soot samples were obtainable for analysis.

EXPOSURE OF PEOPLE TO FIRE GASES (PROJECT SMOKE)*

"Project Smoke" refers to a series of investigations into the acute and chronic consequences of exposure of civilians and fire fighters to the fire atmosphere. The

*This study is under the direction of Drs. M. Levine and E. P. Radford, Jr. (The Johns Hopkins University, School of Hygiene and Public Health).

acute effects of exposure to the fire atmosphere may be determined either by measuring levels of exposure to toxic gases or by analyzing the medical consequences of such exposures and correlating the findings of each approach. The chronic effects of single or repeated exposure can be obtained by a long-term study of heart and lung disease in fire fighters.

Levels of Exposure

The levels of acute exposure to fire atmospheres were measured in 520 fire fighters in the City of Baltimore during a six-month period. Carbon monoxide was selected for measurement as it is ubiquitous in fire atmospheres and is readily taken up by the blood to form carboxyhemoglobin. In order to determine the upper levels of this exposure under actual working conditions on the fireground, blood samples were drawn at the scene of most major fires in Baltimore from fire fighters who had previously volunteered for this study. No alteration in normal fire fighting procedures was involved. The blood samples were then analyzed for carboxyhemoglobin levels.

Our findings indicate that fire fighters are indeed exposed to elevated levels of carbon monoxide and that this occurs whether or not the fire fighters are cigarette smokers (Figures 10 and 11). Neither the amount of smoke present in the fire nor the length of time spent fighting the fire correlated well with levels of carboxyhemoglobin. Since carbon monoxide is colorless and odorless, fire fighters and others may not be fully aware of the potential hazards of exposure to fire-generated gases.

The use of a self-contained, well fitted compressed-air breathing apparatus offers protection from gas exposures. However, masks tend to be worn intermittently due to the circumstances of the fire. Our findings show that intermittent use of the mask is associated with elevated carboxyhemoglobin levels and tends to reverse the protective effect of mask wearing.

Men with the highest carbon monoxide intake differ from the rest of the study group in their more frequent heavy smoking histories and/or less frequent use of protective masks.

These findings indicate that the design of breathing apparatus must be improved so that it may be used more easily and for longer periods of time. In addition, attention should be paid to proper procedures for mask use.

Consequences of Exposure

Outcomes of acute exposures were determined from hospital records of fire victims in Baltimore City. Four hundred and fourteen persons were on record with the Fire Department as having been involved in a fire during the 14-month period from January 1973 to March 1974. Fourteen refused any aid or treatment and 25 could not be traced (Figure 12). Of the remaining 375 victims who were taken to the hospitals, no record was available of the exact treatment of 29 patients. Thus, the course of 346 victims was followed in detail.

Approximately 15% of the casualties from fires (55) did not survive. Of the

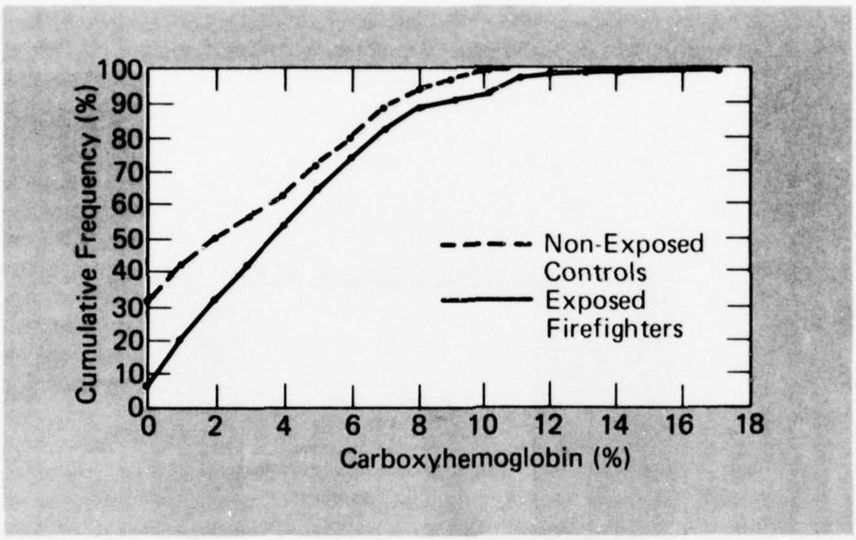


FIGURE 10 Cumulative frequency distribution of COHb levels in fire fighters and controls (cigarette smokers).

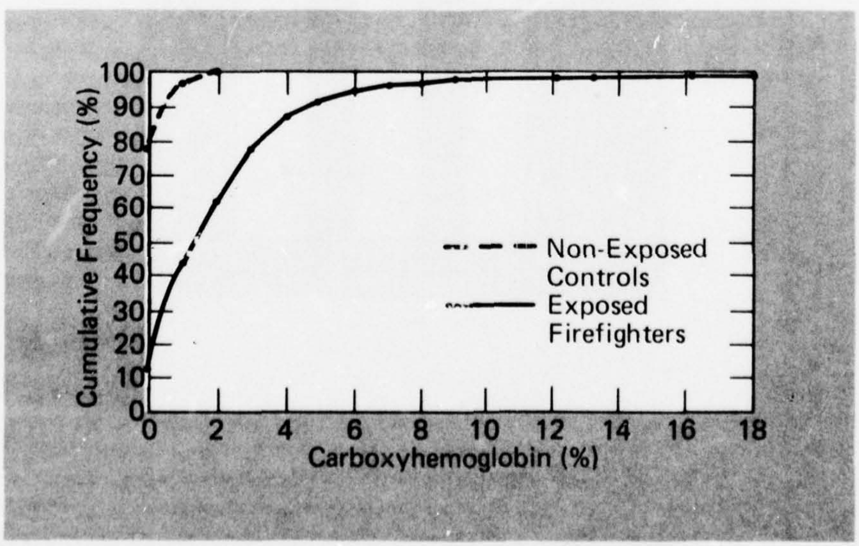


FIGURE 11 Cumulative frequency distribution of COHb levels in fire fighters and controls (non-smokers).

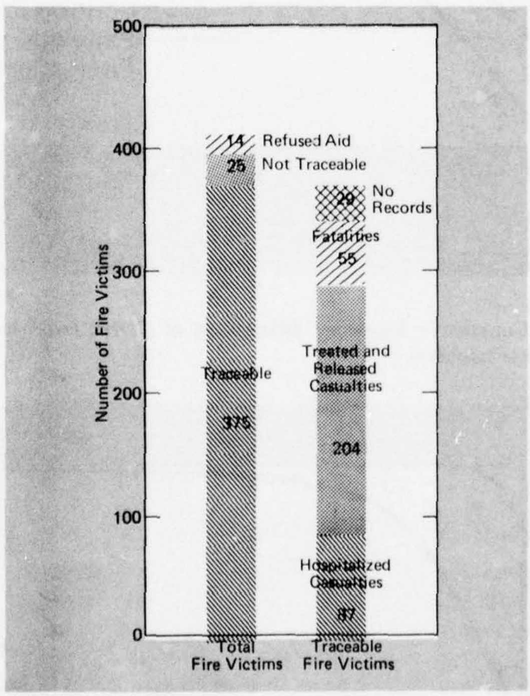


FIGURE 12 Analysis of hospital records on fire victims in Baltimore City, Jan. 1973–Mar. 1974.

55 persons who died, 80% survived for less than one day, and the remaining 20% received more extended hospital treatment prior to their demise. Approximately 25% were hospitalized for treatment (87), and the remaining 60% were treated and released. The ratio of hospitalized casualty cases compared to fatalities (87/55) is substantially lower than is generally quoted in published estimates of fire injuries. In the majority of fatal cases, the primary cause of death as determined by autopsy was inhalation of the toxic products of combustion. However, survivors suffered most frequently from burn injuries (Figure 13).

Chronic Effects

The results of chronic exposure to the toxic products of fire atmosphere is of great interest to fire fighters. To estimate the long-term effects of such exposures, we have initiated cross-sectional epidemiologic studies of the occurrence of chronic heart and lung disease in fire fighters. These investigations are now in progress and involve measurements of pulmonary function, blood pressures, and electrocardiograms, as well as a detailed health questionnaire. These findings will be corre-

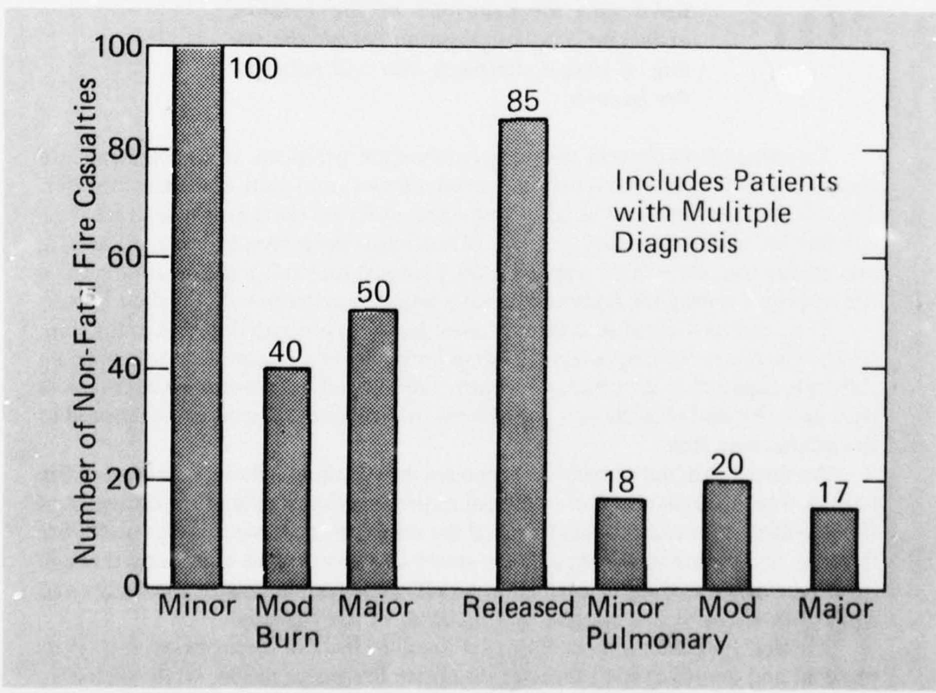


FIGURE 13 Diagnosis of fire injuries in Baltimore City, Jan. 1973—Mar. 1974.

lated with the degree of exposure to fire atmospheres. Mortality studies are also in progress to determine if any specific cause of death can be related to the fire fighting occupation as, for example, quantity of exposure.

The data from this broad series of investigations will provide a comprehensive view of the acute and chronic consequences resulting from inadvertent or occupational exposure to the fire environment and may suggest means for their prevention and control.

COMBUSTION RESEARCH

Fires are a subdivision within the field of combustion. What distinguishes them from the better understood uses of controlled combustion in engines or furnaces are the wide variations in fuel types, fuel arrangements, ignition sources, and gas flow patterns. Insights into the principles of fire ignition, extinction, and propagation permit the setting of design standards that will minimize fire hazards.

Unwanted fires present complex combustion problems whose elements are chemical kinetics, thermodynamics, aerodynamics, and heat and mass transfer. The research problems can be addressed on many levels. On the most abstract level, combustion can be described in terms of molecular processes: collision, radiation, and energy transfer. On the applied level, combustion studies can be as direct as a fire inspector testing the flammability of a building material with his cigar lighter.

Fires can be divided into three phases: ignition, propagation, and extinction. Ignition is the process by which a system passes from a nonburning to a burning state; propagation is the process by which a developed fire consumes the reactants (fuel and air); and extinction is the process in which a developed fire is reduced to the nonburning state.

An understanding of ignition processes would allow better assessment of fire hazard. The understanding of combustion propagation would allow estimates of times available for escape from fires and the response times required for useful fire fighting, and evaluation of the relative safety of areas in a fire and routes through fires. An understanding of extinction would allow estimation of the forces and equipment required and suggest new methods of fire fighting.

Physical and chemical processes are involved in all of these phases. However, physical and aerodynamic processes dominate fire propagation, while chemistry dominates ignition and extinction. Since our interests lie in the chemical area, we have emphasized ignition and extinction in our program.

Specific studies have included ignition and extinction of polymer flames using

a new method called the "Moving Substrate Technique." Since most domestic fires are ignited or sustained by either natural or synthetic polymer fuels, this represents an important practical problem. A second area has been flame inhibition. Inhibitors are chemicals which reduce the propagation rates of flames and are used in a number of commercial fire extinguishers. The understanding of the chemistry of these processes could provide important clues leading to new extinguishing agents. A third area has been the determination of rates at high temperature of some elementary inhibition reactions. This is useful because fire models use kinetic information which often needs to be extrapolated from low-temperature studies in the absence of high-temperature data. A new technique, the "Point-Source Method," has been developed which allows the study of rates at flame temperatures from which the reliability of extrapolated chemical kinetic information can be assessed. The fourth area involves developing models of simplified flame theories which can be used to predict the chemical effect of inhibitors.

THE MOVING SUBSTRATE TECHNIQUE — A NEW METHOD FOR STUDYING ABLATION, IGNITION, AND EXTINCTION OF POLYMER FLAMES*

One of the major interests of the fire program has been the understanding of polymer behavior during ignition and extinction. The complexity of solid fuel — gaseous oxidizer systems and the transient nature of ignition and extinction has made quantitative studies difficult heretofore. In the past, systems were commonly studied transiently or critical time-to-ignition parameters were determined, but the short times available for measurements have presented a difficult measurement problem.

A new method called the Moving Substrate Technique (MST) has been developed at APL for studying these transients. The basic concept is to exchange transient time dependence for steady-state position dependence. This is accomplished by moving the material to be ignited relative to a stationary, well-characterized ignition source. The polymer in the form of a wire is drawn through an ignition source such as a flame of known temperature and composition. Positions across the flame in the direction of wire travel correspond to increasing residence times in the ignition medium. Time at a particular point in the flame can be controlled by changing wire velocity. This provides flexible control of ignition and extinction phenomena.

Two classes of behavior are observed: stable and metastable. With stabilized phenomena, there is a one-to-one correspondence between position along the wire coordinate and residence time. Precise measurements are possible because the time available for experiment is primarily limited by convenience. Precision varies with the square root of measuring time. Metastable behavior occurs where a given residence time corresponds to more than one state of the system. This is the result of

*C. Grunfelder, Dr. H. Schacke (Göttingen University), and Dr. L. W. Hunter contributed to the development of the Moving Substrate Technique.

positive feedback which occurs in many physical systems. In polymer combustion, the feedback results from the coupling between polymer volatilization and the heat released by its combustion. If volatilized polymer enters a suitable oxidizing atmosphere, heat is released. This heat raises the gas temperature, which in turn increases the heat transferred to the polymer surface, resulting in an increased volatilization rate. This process bootstraps itself until a new balance is reached in a stabilized polymer flame. The MST is useful even with such bistable phenomena because it allows definition of the hysteresis loops.

The use of moving systems stabilized in fixed laboratory coordinates to study steady-state combustion is as old as the bunsen burner and the automatically stoked furnace. The concept has also been used in wood cribs, polymers, and fabrics. It appears to be new, however, in the study of ignition and extinction.

Apparatus

Flame-piloted ignition was studied, since flames provide both high temperatures and nonthermal excesses of reactive species such as atoms and radicals. The apparatus can also be adapted to other ignition sources such as hot gas jets, radiant fluxes, or electrical arcs. Polymer ignition requires: (a) volatilization, (b) a second reactant, (c) mixing of volatilized fuel and oxidizer, and (d) high temperature and radical concentrations to initiate combustion. Flames can supply these requirements. Ignition can occur in the wake of a wire if sufficient oxygen is available or at the boundary with an oxidizing atmosphere.

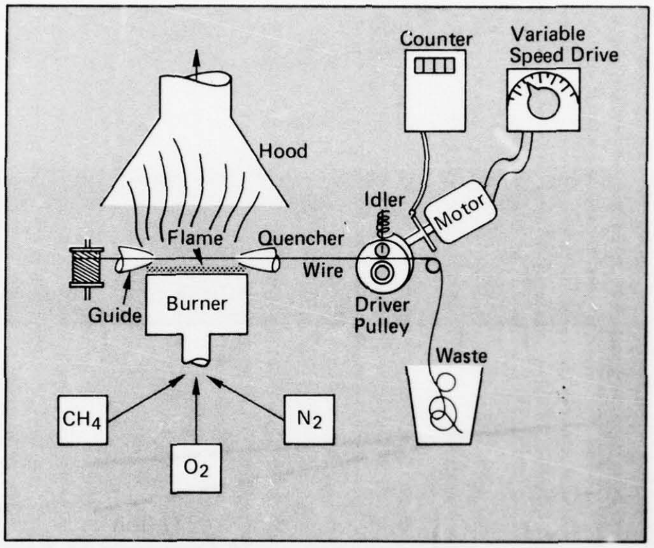
Two versions of our apparatus are used (Figure 14): an isolated burner (14A) or a burner with an adjacent oxygen-containing atmosphere (14B). The composition and temperature of both the flame and the adjacent atmosphere are controllable and adjustable. The substrate to be ignited is in the form of a polymer-coated wire which is pulled across the flame by a mechanism similar to one used in tape decks. A variable speed motor controls velocity which is measured with an optical counter mounted on the drive shaft. With a precision drive and accurate control of composition of the flame and atmosphere, exposed length of polymer, etc., the transition times are reproducible within a few parts in a thousand.

Data

Characteristic transition times (Figure 15) determined with the two experimental arrangements are discussed below.

A — Isolated Burner Experiments

Two behaviors are observed: ablation-extinction transitions and ignition-extinction transitions. Ablation-extinction occurs in oxygen-poor flames and is reversible. Here, when the wire speed is decreased, a characteristic velocity is found at which visible attack begins. The involvement length increases with decreasing velocity. Involvement is reversible, and extinction occurs at the same velocity at which ablation began.



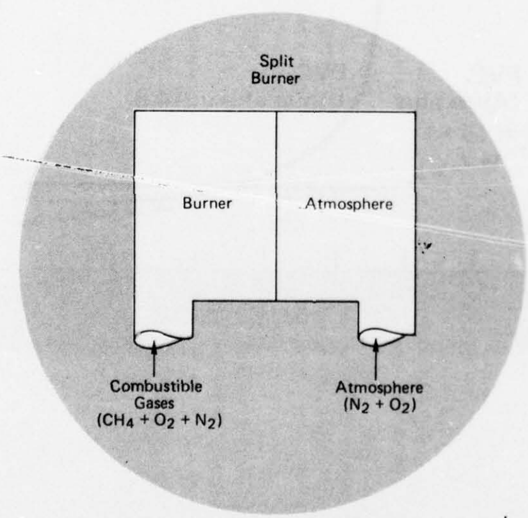


FIGURE 14 Schematic diagram of apparatus for the measurement of ignition characteristics of polymer-coated wires.

(A) Premixed flat circular flame as ignition source.

(B) Premixed flat semicircular flame with adjoining atmosphere with adjustable oxygen concentration.

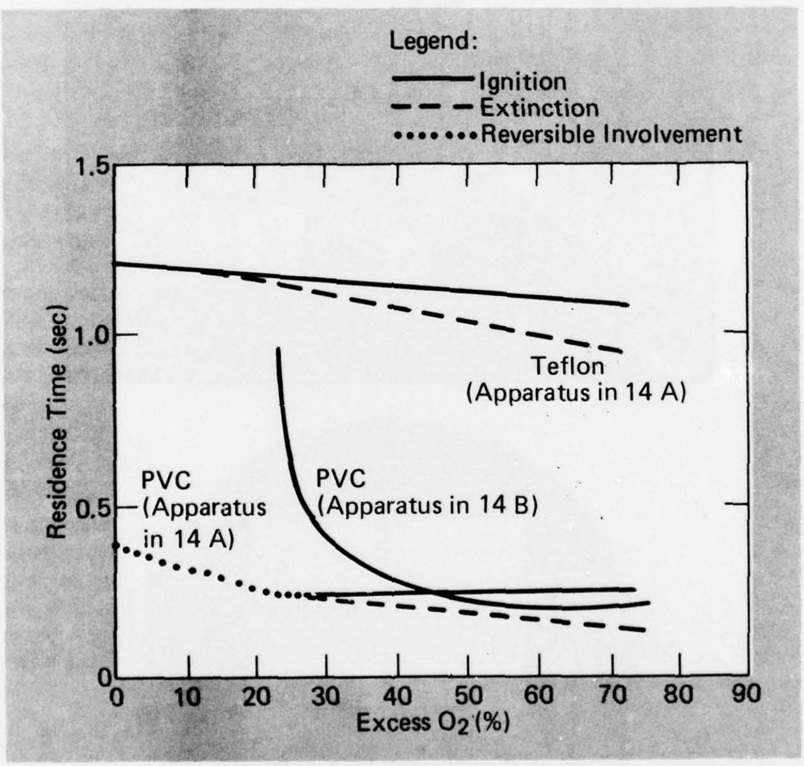


FIGURE 15 Ignition and extinction transitions of three commercial polymer-covered wires. Residence time is shown as a function of composition of the ignition gases.

Ignition-extinction behavior occurs in oxygen-rich flame atmospheres and shows hysteresis. As the wire velocity is decreased, a sharp involvement point is observed. Movies show that ignition begins at the far edge of the flame and propagates back along the wire. After ignition and at a critical velocity and/or flame size, extinction occurs. The extinguishment velocity is higher than the ignition velocity so that a bistable region exists (Figure 16). Temperature measurements in the gas phase and on the polymer surface have shown that this hysteresis behavior is reproducible, and that the sharpness and reproducibility increases with oxygen concentration.

B — Flame — Atmosphere Experiments

If a flame is bounded by an atmosphere containing a higher free oxygen concentration, similar behavior is observed. Ignition begins at the flame-atmosphere interface, but propagates along the wire into the atmosphere. At a low oxygen concentration, the flame ablatively attacks the wire prior to ignition, and below a minimum oxygen concentration in the atmosphere no ignition is observed. At higher oxygen concentrations, the ablative attack is reduced until, above a certain level, attack is observed prior to ignition in the adjacent atmosphere. If the flame has a higher free-oxygen concentration than the atmosphere, ignition will occur in the flame rather than the atmosphere, and the behavior will be that of the isolated burner.

C — Comparisons Between Experiments

The critical transition times were reproducible and are characteristic of the polymer. The controlling parameter for ablation and ignition is flame contact time rather than wire velocity or flame width. Extinction, in contrast, showed more complex behavior.

In the burner experiments, both flame temperature and the concentration of excess oxygen were important, while in burner-adjacent atmosphere experiments, flame temperature and oxygen concentration of the atmosphere were important variables.

Discussion

The moving substrate apparatus lends itself to many measurements which can be characterized by velocity, temperature, and composition of the ignition source and polymer as a function of position. Such measurements should be interpretable in terms of rates of elementary processes of heat transfer and reaction. This interpretation will require a quantitative model which we are attempting to develop. Preliminary studies suggest that ignition is governed principally by the wire surface temperature.

The correspondence between space and time is not exact in this system. Transport phenomena such as diffusion and thermal conduction behave differently in spatially-varying and time-varying systems. In transient systems, future events do

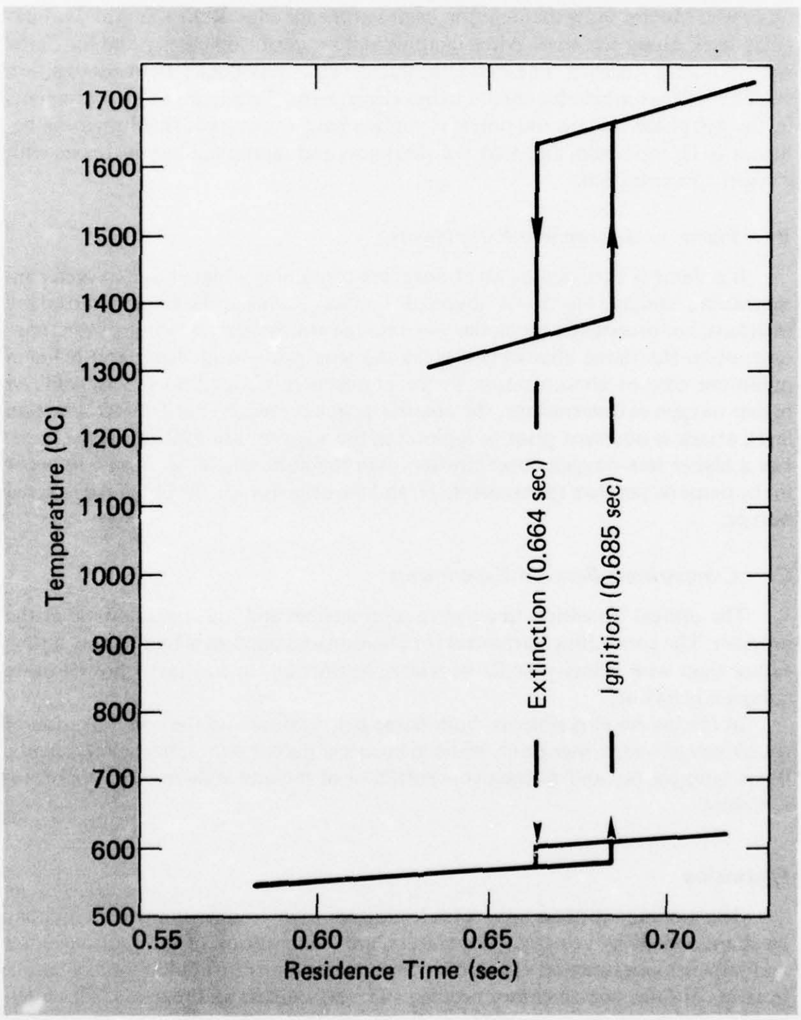


FIGURE 16 Temperature hysteresis at ignition and extinction of No. 30 Teflon wire. Arrows indicate irreversible transitions.
Upper curve: gas phase temperature.
Lower curve: *wire surface temperature.*

not affect on-going ones. By contrast, in a steady-state moving system, diffusion or conduction can produce a profound effect on spatially earlier parts of the system.

Phenomena which show hysteresis (i.e., bistable systems) can only be held metastably in a moving system. The MST, however, offers a powerful tool for accurately defining the critical conditions and investigating stability and hysteresis. This technique provides experimental clarification of the physical reasons underlying the asymmetry between ignition and extinction. The behaviors observed seem worthy of comment: (a) ablation which occurs at low oxygen concentration is a reversible attack of the polymer, and (b) ignition-extinction, which occurs at high oxygen concentration, is a bistable phenomenon showing hysteresis (Figure 16). This clearly shows the contribution of the polymer combustion to produce a bistable situation depending on the presence or absence of the polymer flame. By contrast, in the ablation regime, either the sum of heat required to volatilize the polymer and the heat liberated by its combustion is negative, or the volatilized polymer is swept away from the polymer surface before it has a chance to react. As a result, bootstrapping does not occur, and the behavior is reversible. Most polymers show indications of an ablation regime if sufficiently fuel-rich flames are employed.

The complete interpretation of moving substrate experiments will require extended experimental and theoretical studies. Analysis of the products generated at various positions (or temperatures) in the absence or presence of inhibitors should give information about the function and mode of operation of inhibitors and provide a better, more scientific understanding of flammability tests.

FLAME INHIBITION STUDIES*

Fires are commonly extinguished by physical methods. For example, flooding a fire with water cools it below the temperature at which it is self propagating. Water is effective because it has a very high latent heat of vaporization. In addition, it is nontoxic, cheap, and easily available. Extinguishing a fire with carbon dioxide involves another physical process; the flame is blown out or smothered by a blanket of inert gas which separates the fuel from the oxidizing atmosphere. In addition to such physical extinguishants, there are chemical extinguishing agents whose effectiveness is thought to involve interference with some steps in the combustion reactions. The first of these was carbon tetrachloride, used in hand-pumped extinguishers, but now ruled out because of its toxic properties. Recently several less toxic chemicals have been substituted (CF_3Br and $C_2F_4Br_2$). These are useful because much less material is required to extinguish a fire than would be the case with CO_2 or water. Such agents are advantageous where weight is important (as in airplanes), where water might cause damage (as in computer installations), and in electrical fires where water could produce hazardous short circuits.

The mechanisms of chemical extinguishment is a subject of some controversy; therefore, we have undertaken studies in chemically simple flames to try to identify

*C. Grunfelder, Dr. L. W. Hunter, and Dr. P. van Tiggelen (Professor, University of Louvain laNeuve, Belgium) participated in this study.

the important processes. We chose to study CF_3Br, one of the most widely used chemical extinguishants. In chemical research, flames are studied far short of the extinguishment point, since it is difficult to study flames at the point of extinction. The slowing of flame reactions short of extinction is called inhibition. One common interpretation is that inhibitors interfere with radical reactions involving molecular fragments that occur in flames and in other rapidly reacting systems.

Characteristically radicals have an odd number of electrons and show high reactivity. Therefore, molecules which destroy or interfere with the production of radicals might inhibit flame propagation. One common mechanism is called the "scavenger reaction," where the inhibitor reacts with the flame radicals (e.g., H, OH, and O), converting them into unreactive radicals, e.g., Br. An example is the reaction of OH with HBr:

$$OH + HBr \rightarrow H_2O + Br.$$

Other radicals, such as H and O, undergo similar reactions with an inhibitor species.

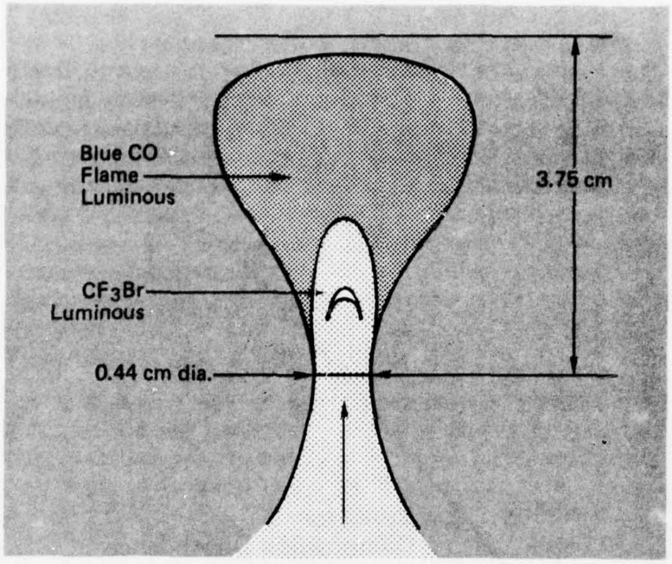
Scavenging reactions neutralize reactive radicals on a one-to-one basis. In another class of reactions which can destroy radicals by a chain recombination process, one Br atom, for example, can recombine and thus inactivate many radicals. The scheme is as follows:

$$\begin{array}{c} H + Br + M \rightarrow HBr + M^{*}\text{(slow)} \\ \underline{HBr + H(O,OH) \rightarrow H_2(OH,H_2O) + Br\text{ (fast)}} \\ H + H(O,OH) \rightarrow H_2(OH,H_2O)\text{ net reaction} \end{array}$$

Note that the net result of the two reactions is the destruction of radicals and that the catalytic agent, Br atoms, is regenerated. The limiting slow step is the three-body recombination.

The APL study has involved a structural measurement of a low pressure $CO\text{-}H_2$ diffusion flame inhibited by CF_3Br (Figure 17A). At the University of Louvain laNeuve, Belgium, a parallel study of the structure of similar inhibited detonations and premixed flames is underway. Diffusion flames result when fuel and oxidizer are initially separate. The reaction rate is controlled by diffusional mixing. Most industrial flames and fires are of this type. Since fuel and oxidizer are introduced separately, the inhibitor can be added to either the fuel or the oxidizer. Different behaviors are obtained which may have important consequences in fire fighting. The inhibitor was found to be more effective on the fuel side in this system, and studies were concentrated there. Structural studies showed that the inhibitor was destroyed ahead of the main flame reaction zone in a narrow zone associated with a bright azure luminosity (Figure 17B). The position of this luminosity was a function of the inhibitor concentration, but was independent of the pressure (Figure 18). The attack of CF_3Br was attributed to reaction with H atoms. A simple theory was developed which explained the observed behavior and allowed an estimate of the level of H atom concentration in the reaction zone. The proposed mechanism for CF_3Br destruction was:

$$\begin{array}{lll} H + CF_3Br & \rightarrow Hbr & + CF_3 \\ H + CF_3 & \rightarrow CF_2 & + HF \\ CF_2 + O_2 & \rightarrow COF_2 & + O \end{array}$$



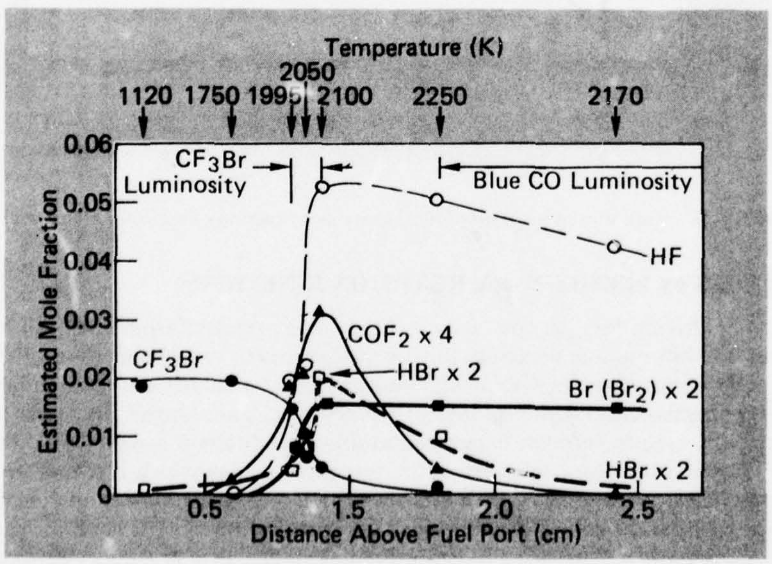


FIGURE 17 Low pressure carbon monoxide-hydrogen diffusion flame inhibited by CF_3Br.
(A) *Flame structure.*
(B) Composition and temperature profiles.

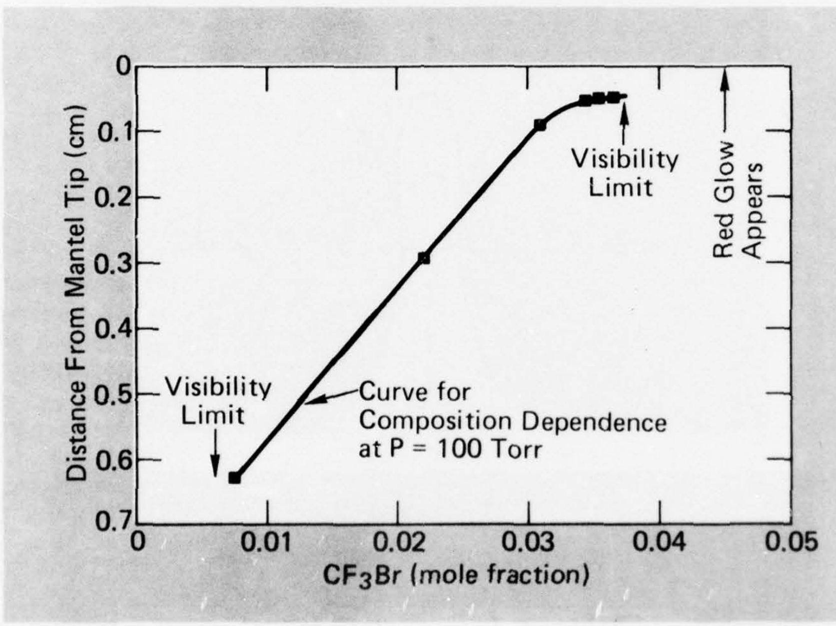


FIGURE 18 Variation of position of luminosity as a function of inhibitor concentration.

STUDIES IN ELEMENTARY REACTION KINETICS*

The driving force in combustion is the energy released from chemical reactions. The information necessary for fire models are the reaction mechanisms and the rates of the elementary steps. In physical chemistry studies, rates usually show an exponential dependence on inverse temperature. This "Arrhenius relation" is commonly used to correlate experimental studies at different temperatures. From the slope of such plots, one derives the activation energy which is related to the energy barrier for the reaction, and from the intercept one obtains the frequency factor which is the rate of reaction given sufficient collisional and internal energy. For many purposes this is a good approximation, but there is some evidence of a breakdown of the relation for reactions that occur at the temperatures found in flames. This is a serious problem in combustion models and fire applications

*N. deHaas, C. Grunfelder, Dr. L. W. Hart, and Dr. A. A. Westenberg conducted the research reported in this section.

because most high temperature reaction rates are derived by extrapolation from low temperature measurements.

To investigate the seriousness of this problem and add kinetic information of interest in flame inhibition, we developed a new technique called the "Point Source Method." This uses the flame gases as a wall-free high temperature radical source. A small flow of the molecule under study is injected into a flame of suitable and known temperature and radical concentration and the decay of the reactant is measured as a function of distance from the source (Figure 19). This information can be interpreted in terms of elementary rate constants in a temperature regime (1000 to 2500 K) which is difficult to obtain by other methods. We chose to study the reaction of H atoms with methyl halides.[7]

To further investigate this problem and validate the new technique, a companion study of the same family of reactions was undertaken using the well-established, high-precision Electron Spin Resonance-Flow Reactor Technique.[8] This method consists of a low-pressure flow tube in which reactants are mixed rapidly with a radical in excess, the reactants-radical reaction allowed to proceed, followed by electron spin resonance detection of the unconsumed radical species and mass spectrometric detection of stable species. This technique has generated

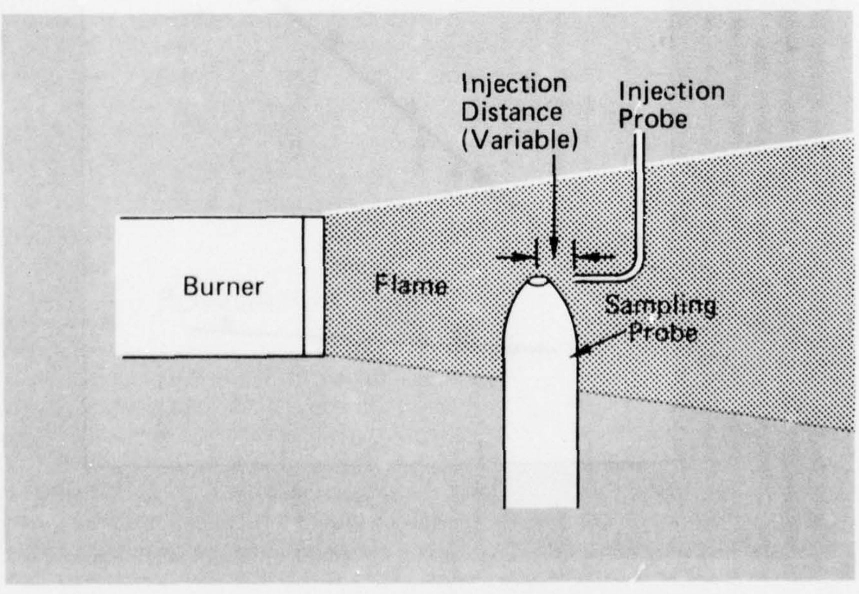


FIGURE 19 Schematic diagram of point source injection apparatus for studying radical-molecule reactions in flame environments.

some of the most precise and reliable elementary kinetic information. The study was aimed at obtaining as wide and as high a temperature range as possible, with measurements extended to 1000 K by heating the flow tube. This allowed an overlap with the point source studies, with gratifying agreement between the two studies (see Figure 20). In the overlap region, the absolute values agreed within a factor of two and relative rates between species, that did not depend on an absolute measurement of hydrogen atoms, agreed within 30%. This agreement between the two widely differing techniques suggests that the point source method can give precise relative rates, with absolute rates derived with known comparison reactions. It also indicates that the Arrhenius extrapolations of reaction rates to temperatures found in flames are valid.

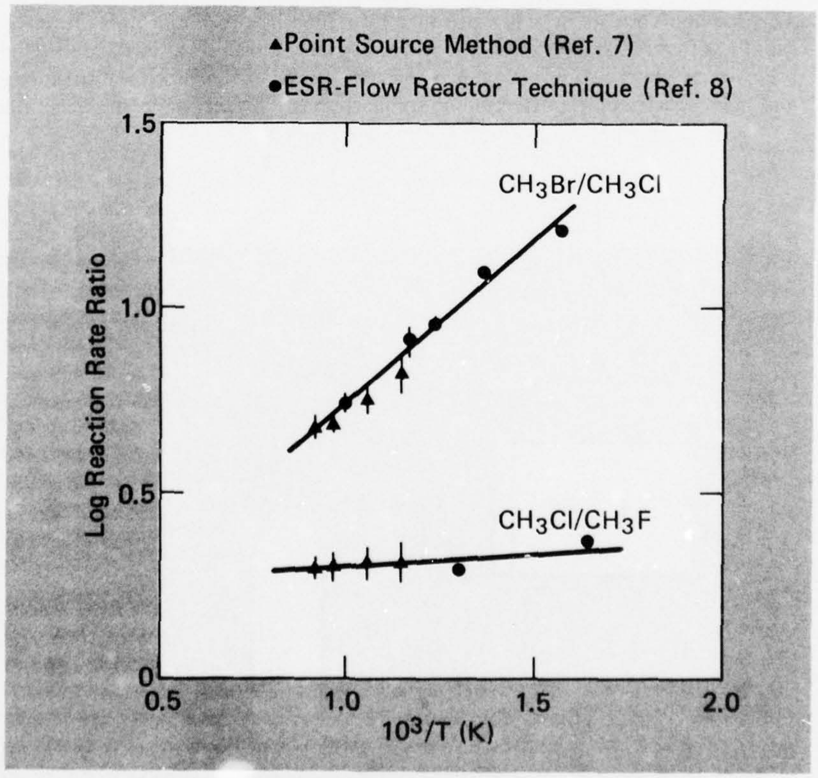


FIGURE 20 Rate constant ratios as a function of temperature determined by two independent experimental methods.

FLAME THEORIES*

Many fire protection engineering problems require realistic mathematical models of fire situations. The elements of these models are the various basic physical and chemical processes. Fire models can be divided into several interacting parts: flow field, flame reaction region, radiation field, etc. One important component is the flame. Because of the combined complexity of the overall problem and the theory of flames, it is customary to avoid the flame chemistry by treating the flame reactions as a single empirical adjustable parameter. This simplification is desirable because rigorous flame theory, even in a one-dimensional form, is limited to a few chemical steps unless expensive, high-capacity computers are employed.

To improve this situation, we have developed a model for flames which simplifies the physical aspects so that more realistic chemistry can be used.[9] The model assumes that the flame can be approximated as a homogeneous reactor with calculable average properties. The conditions for flame propagation are taken to be those which allow maximum throughput. In a flame this is equivalent to assuming that the reactions are confined to a narrow homogeneous region, and that the flame propagates at the maximum rate compatible with conservation restrictions. Experimental studies of flame structure support this model, although in some cases more than one reaction zone needs consideration. This reduces the flame problem from the solution of a strongly coupled set of partial differential equations to the solution of a coupled set of algebraic equations. Calculations may be made of the composition, temperature, propagation velocity, and thickness of the primary reaction zone. The computer capacity required for these calculations is reduced by more than an order of magnitude when compared with conventional flame theory calculations.

The model has been applied to hydrogen-air flames where measurements of the burning velocity and hydrogen atom concentration in the reaction zone are available. The agreement between theory and experiment is excellent. By using the second approximation involving coupled reaction zones, it was possible to make the calculation without the use of adjustable parameters. The model has been extended to hydrogen-air flames inhibited with HCl. Again the agreement between predicted and measured changes in burning velocity was good.

EXPERIMENTAL STUDIES AND SURVEY PAPERS

Several new experimental techniques have been developed at APL in support of the fire program. They include: (a) a phase-adjustable sampling mass spectrometer for studying the time behavior of repetitive phenomena such as spark ignition;[10] and (b) a large-area, laser-illuminated differential interferometer for investigating flow and density fields around model fires.[11] The extension of this technique to full-scale burns was investigated, and it was concluded that the use of a one-watt continuous-power visible laser would allow study of a field 10 meters

*Dr. Nancy Brown and Professor R. Sawyer (University of California, Berkeley) participated in this study.

Specific studies have included ignition and extinction of polymer flames using

by 10 meters. A third technique is a method of sizing particles using interferometric fringes.[12] This could prove a useful tool in soot and smoke studies.

SYSTEMS ANALYSIS AND DEVELOPMENT

Combating fires bears many resemblances to warfare. Fire suppression forces must be deployed effectively so that countermeasures can be taken quickly. Devices that improve command and control at the fireground are urgently needed.

The logical sequence of events involved in a fire, in the absence of an automatic response leading to its suppression, are:

Ignition of some combustible materials
Detection of a fire
Alarm to a fire-fighting organization
Dispatch of fire-suppression equipment
Response of men and equipment to the fire scene
Estimate of the seriousness of the situation (size-up) on the fireground
Fireground operations (rescue and suppression)
Overhaul (salvage, cleanup, securing operations)
In service (release of men and equipment for other assignment)
Return to quarters
Post-fire critique

The events can be regarded as demarcation points between separate phases. In actual practice, the duration of a given phase can be quite variable. There can be an overlap of events or a repetition or superposition of a cycle of events.

The fire department becomes involved in a fire at the time the alarm is given. A prearranged response of men and equipment will be dispatched which, in most jurisdictions, is already decided upon as a function of the type of alarm that is received. For example, if an alarm is given for an apartment complex, a specific number of men and equipment are preprogrammed to respond. It will be larger than the initial response to a single dwelling since a more hazardous and complex situation is likely to prevail.

The APL/JHU Fire Group has examined several segments of the fire department operation. Since the investigation had to have the cooperation of fire suppression organizations, the areas of investigation were dictated by the joint interest of local fire departments such as Baltimore City and the Hillandale Volunteer Fire Department in Montgomery County. Two major topics dealt with were: Fireground Command and Control System and Communications and Response Analysis.

FIREGROUND COMMAND AND CONTROL SYSTEM*

In many communities the number of men and units of equipment that will respond to fires may be sizable because of the existence of large apartment complexes and high-rise buildings, hospitals, schools, shopping centers, and commercial structures. The initial response alone can present a formidable challenge to the officer in charge of the fireground operations. In a severe fire many units will respond; not all of the units are visible or in direct communication with a command post, nor are they necessarily all from within the fireground commander's own jurisdiction.

The first requirement for effective fire suppression command is for fire officers to know what is to be controlled and what means are available to them. Under the conditions of stress and confusion induced by the emergency, it often becomes difficult to assess the variables that control the proper deployment of resources. Key decisions may be omitted from the command operation because the officer in charge is not able to appraise conditions rapidly and properly. Often the commanding officer does not have all the essential information at hand to develop the best operational procedures.

It has been stated that prior knowledge of variables associated with an emergency could increase the effectiveness of fire department operations more than any other single factor.[13] For effective emergency command, a fire officer must first have knowledge of pertinent facts and then optimize existing and available tools. The resulting tactical or command decisions must then be communicated to support units. Maps, charts, and radio messages are used extensively to assist commanding officers. However, even with such aids, many decisions are formulated without adequate supporting information.

Decision-making abilities vary from officer to officer, depending on his talent, experience, and training, and on the extent and quality of tactical preplanning before emergency situations arise. It is beneficial to place as much information as possible at the disposal of the fireground commander to aid him in reaching sound decisions. The response territory (including street and building layouts), locations of private fire protection equipment, special hazards and water supplies, exposure conditions, and extent of mutual aid support should be available to the fire officer when responding to a given incident.

The problem of handling both prefire planning data and of displaying the disposition of a sizable force of men and equipment in action on the fireground in an economical and reliable way has resulted in the design, fabrication, and evaluation of a fireground command and control system. The system comprises various components that can be used independently. The first component is a portable Tactics Display Case[13,14] that contains aerial photographs of target hazards marked with standard symbols for features of interest (e.g., gas, water, and electric cutoffs, hydrant location, special hazards, blocked entrances) together with magnetically attachable markers for indicating the placement and availability of individual

*Professor H. E. Hickey (University of Maryland) and D. O. Shapiro participated in the developments described in this section.

fire department vehicles. It is thus possible for a fireground commander to assemble an up-to-date display of the fireground and the status and location of the units under his command. The display case can also be used for preplanning and debriefing operations and in training exercises.

When a portable microfiche reader, displaying important background information on designated hazards, is used in conjunction, the resulting configuration is called the Tactics Display Console. This information would indicate inspection reports, prefire planning data, occupancy data, floor plans, locations of special hazards, priority salvage instructions, or any other information of interest for the various structures that might be involved in fires. The Tactics Console is small enough for mounting in the cab of a fire engine or in a Chief's car.

The most elaborate configuration developed to date consists of a Tactics Console and other instrumentation in a specially designed and outfitted vehicle called the Mobile Tactical Unit for use as a mobile command, control, and communications vehicle. The outfitting of such a vehicle has been a joint project with the Hillandale (Maryland) Volunteer Fire Department (HVFD) which furnished a ¾-ton Ford Econoline van equipped with necessary fire-service devices (sirens, safety lights, and radio) and a mobile telephone for contacts with the Command Center. APL, with the advice of HVFD, designed, fabricated, and installed a status display panel, three microfiche readers, a rotating and sliding aerial map board reader, meteorological and hydraulic sensors and display meters, cabinets, chair, hardware furnishings, and a Mine Safety Appliances Co. gas analysis kit.

The Mobile Tactical Unit was formally transferred in March 1974 to the Hillandale Volunteer Fire Department (Figures 21, 22, and 23) for evaluating the equipment components and the procedures for use under emergency conditions.

COMMUNICATIONS AND RESPONSE ANALYSIS*

No fire department can function efficiently without effective communication. With the cooperation of the Baltimore City Fire Department, a study was undertaken to examine the equipment and procedures used in the alarm and dispatch phases.[15]

Conclusions of the study were that the general alarm and dispatch techniques were adequate to cope with the Baltimore City fire problems for the foreseeable future. However, it was found that the most glaring problem was in outdated communication equipment, especially on the fireground apparatus. The communication equipment available did not have enough channels available to pass pertinent information. As a result, there are built-in bottlenecks for information transfer.

An investigation of the extent, the causes, and possible remedies for false alarms was carried out. Such alarms are becoming increasingly prevalent in cities and put a great strain on available resources. The characteristics of false alarms in Baltimore were reviewed using the street-box alarm data for July 1, 1971, through June 30, 1972. The original data consist of dates and times of day when alarms were pulled, but the time distribution of alarms had not been obtained. In order to

*Dr. G. L. Ordway and J. W. Hamblen conducted this study.

FIGURE 21 Mobile command and control van in Hillandale, Maryland, Volunteer Fire Department station house.

FIGURE 22 Internal view of mobile command and control van showing aerial photo board and equipment status board, looking from back to front of the van.

wires. Residence time is shown as a function of composition of the ignition gases.

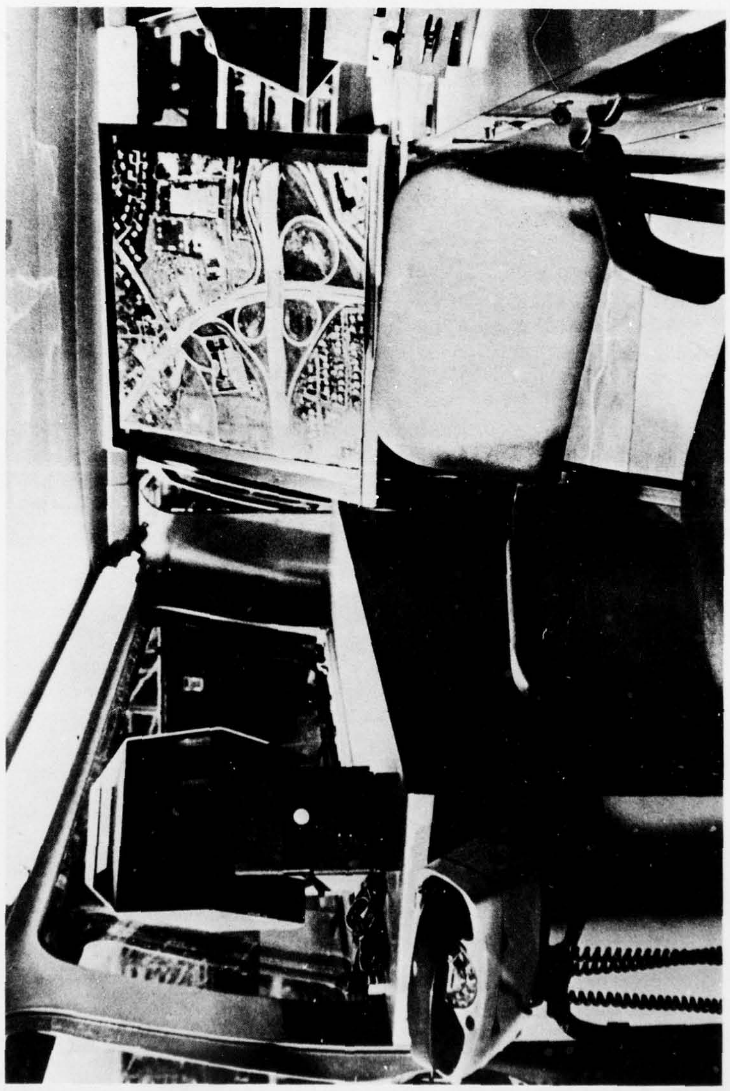


FIGURE 23 Internal view of mobile command and control van with aerial photo board in position for use, with microfiche readers evident.

look at the spatial distribution of alarms, annual totals of false and fire alarms were compiled for each section of a map grid.

The data compiled for the 1585 street alarm boxes for which there were alarm data were summed for each of the 102 grid sections of Baltimore, and the total false and fire alarms for the year were obtained.

Totals for the entire city are as follows:

Number of boxes reported	1585
Number of false alarms	5488
Number of fires	3009
Total box alarms	8497
Percent false alarms	64.59
Ratio false/fire	1.82
Total alarms per box	5.36
False alarms per box	3.46

Note that these are alarms for street boxes only. About two-thirds of the alarms received by the Fire Department are "silent" (by telephone) alarms, and of these only about 10% are false.

With regard to the false-alarm data, various criteria of false-alarm activity have been tested, and an attempt is being made to group data on a less arbitrary basis and to associate the results with demographic factors.

It was suggested that different types of alarm boxes might show different kinds of alarm data; accordingly, the data were sorted by box type. It was conjectured that quick-pull boxes, because of their relative ease of operation, might have a higher proportion of false alarms. It was found, however, that there is no significant difference in the ratio of false alarms to fires (f/t) between the three-fold and quick-pull circuits, and f/t is lower for sequential circuits. There is a significant difference in alarm densities; the number of total alarms per box is about 50% higher for quick-pull and sequential boxes than it is for the three-fold type. This may be due to the distribution of different box types throughout the city, which has not yet been investigated.

INFORMATION AND EDUCATION*

Human participation, human behavior patterns, and human judgments play important roles in the ignition and extinction of fires. The instruction of people in the technical intricacies of fire-related matters presents a challenge that requires a variety of approaches.

When the NSF/RANN programs on Fire Research were initiated in 1970, it was recognized that, apart from the all too fragmentary knowledge of under-

*B. W. Kuvshinoff and Dr. R. L. Tuve contributed to the work described in this section.

lying physical, psychological, and medical facts, another serious problem needed to be attacked—namely how to lower a communication barrier that then existed between the practitioners in the fire field and the research people whose function is to advance the understanding of its basic principles. Similar gaps existed between the fire community and the general public on matters of fire safety and prevention. Not least, within the specialized audiences making up the various subsections of the fire field there is need for better exchange of information on intentions, accomplishments, and results.

The APL attack on these communication barriers proceeded along a number of separate paths:

1. The Washington/Baltimore metropolitan area, with APL located near its geographical center, contains within its boundary a wide variety of urban, suburban, and rural fire departments, one University and a number of Community Colleges concerned with teaching functions in the fire field, several Fire Research Centers (such as the Fire Center of the National Bureau of Standards) and many federal agencies with direct or indirect interests in fire problems. It seemed appropriate to furnish to varied audiences a center for the presentation of technical discussions on a wide variety of fire-related themes.

Side by side with large numbers of very practical fire prevention and suppression matters, there are many exquisitely complex physical and chemical problems on the ignition and extinction of flames and their propagation along surfaces which must be worked out to predict and explain the frequently observed generation of smoke or the liberation of toxic combustion products. There exist intricate fluid mechanical and heat transfer processes, such as in fire whirls, that can assume devastating intensities or, as in the case of fully developed heat release in buildings, can cause extensive damage to structures. The effects of fires on living beings, through ingestion of toxic substances or the consequences of burns, are profoundly distressing as are the psychological consequences to fire exposures.

Several dozen colloquia, covering physical and chemical aspects of Fires, Health, and Behavioral Problems, Fire Protection Prevention, Design Principles, and General Reviews have been held at monthly intervals, attracting diverse local audiences to the presentations as well as nationwide participants to several two- or three-day-long Conferences and Workshops where specific topics (Teaching of the Fire Sciences; Fireground Command, Control and Communications; Fire Casualties) were discussed in considerable detail.

As a means of expanding the coverage of the Colloquia series, edited audio and video recordings have been made available, providing an opportunity for building up a "library" of source materials in topics of current interest. This is of particular value to the several hundred community colleges throughout the United States whose faculty and students do not have ready access to new developments in the fire field. It supplies to a student body, numbering in the tens of thousands, and to a large number of practitioners a convenient way to supplement their insights into new developments out of which the technology and science of fires are fashioned.

2. Despite the difficulty of documenting quantitatively the effectiveness of alternate ways of reducing the appalling annual fire losses, it is nevertheless clear

that the majority of the serious human injuries and deaths is due to misjudgments or errors in human behavior. In order to reduce these losses by a substantial amount (the recent federal legislation in the fire field "mandated" a 50% reduction in a generation), a vigorous educational program directed towards the needs of the public appears essential.

An interesting appeal to a specific audience was carried out in the following way: A group of young high-school students, participating in an accredited course in Creative Writing and Film Making, took on the assignment of producing a film for their peers that would present sound fire prevention and safety advice in a manner appealing to youthfully critical audiences. With the guidance of the Montgomery County, Maryland, Fire Marshal and the APL Film and Fire Problems Group, a 23-minutes-long sound-and-color film ("Don't Get Burned") was made on the theme of how to go about producing a film that would have an impact on young people. The project was carried out with such infectious good humor and enthusiasm that the serious messages woven into the story carry a strong impact. (See Figure 24.) The film is distributed widely throughout the United States by the National Fire Protection Association. A sequel, "Don't Make an Ash of Yourself," dealing with inner-city problems has been written by a creative Baltimore student group and awaits funding for final production.

3. A strong leverage position in the transmittal of new information and of a forward-looking practical outlook on fires is held by a rapidly expanding educational group of Fire Science and Fire Technology instructors. This group has only been loosely organized in the past, despite its important place in the training of young people in fire suppression, fire protection, fire administration, and in other related areas. Spurred on by two APL-organized symposia on the "Teaching of the Fire Sciences," where searching questions were asked concerning basic fire science curriculum contents and teaching objectives, qualification standards, student recruitment, innovative teaching methods, and other similar issues, a decision was reached to organize a formal "Association of Fire Science and Technology Instructors" with responsibilities for providing continuing contacts among its members, setting teaching standards, and pursuing high levels of professional performance.

4. An as yet incompletely met need of the fire field is an adequate network of information exchange. With the exception of the services provided by a monthly Soviet Abstract Journal, *Fire Protection*, and of *Fire Research Abstracts and Reviews* (published by the U.S. Academy of Sciences and edited by an APL staff member), it is not at all easy to keep in touch with the relevant published literature. These two cited sources only partially fill the void, leaving out important areas of interest, such as economic, legal, fireground command and fire training issues, and the statistics on losses from which informed planning models could be derived.

To offset this difficulty somewhat, the APL program has generated bibliographic materials of several kinds. The most elaborate part of this effort was the preparation of a *Fire Dictionary and Source Book* in which approximately 8000 terms from every section of the fire field were included. Each is explained in sufficient detail so that the reader can find a way through the maze of highly specialized expressions that may be in common usage in one fire specialty, but which are quite unclear in another. This dictionary is expected to be widely used by the prac-

$CF_2 + O_2 \rightarrow COF_2 + O$

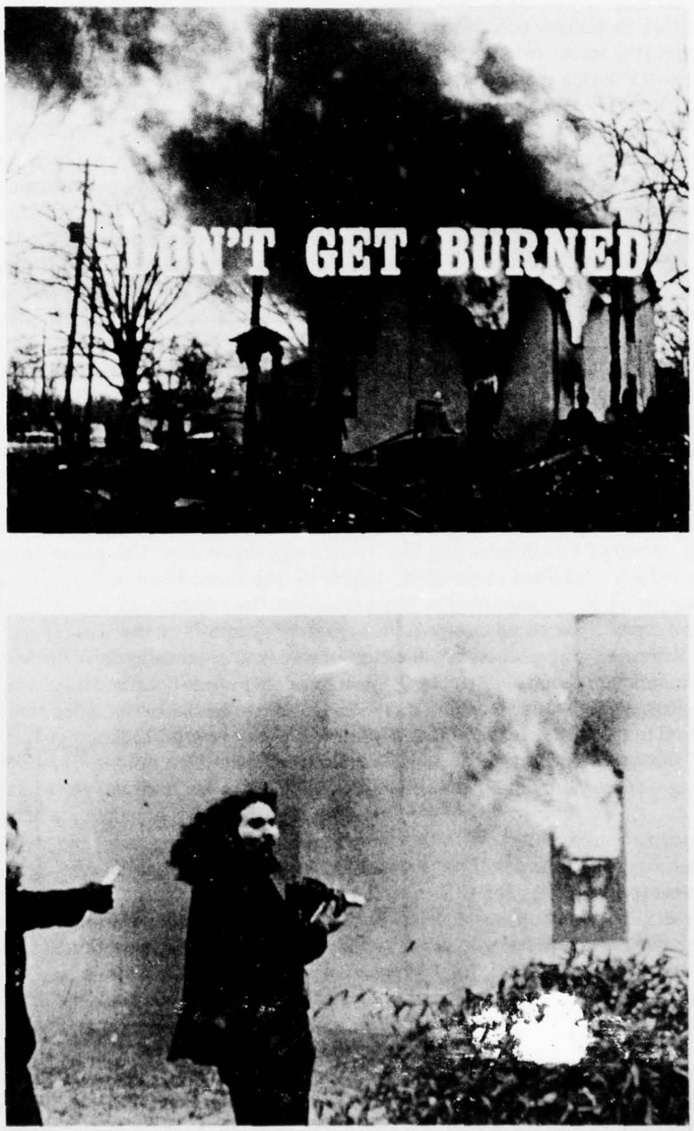


FIGURE 24 Scenes from film "Don't Get Burned."

titioners in the fire field and presents a good start on a syllabus of technical terms. Bibliographies of important parts of the combustion literature, reviews of specific technical fire areas, and a *Source Book on Workers in the Fire Field* make up the remaining inputs.

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APPLICATION OF FIRE/GAS SENSOR DETECTION TECHNOLOGY TO METAL AND NON-METAL MINE FIRE PROBLEMS*

J. P. WAGNER
A. FOOKSON

Gillette Research Institute,
Rockville, Maryland#

INTRODUCTION

The need for reliable and timely detection of the onset of fires in metal and non-metal mines cannot be underscored too greatly in light of an earlier major disaster from fire and smoke contamination at the Sunshine Mine in which 91 men died (the worst fire tragedy in the U.S. in 1971).[1,2] Although it may be argued that this represents a statistical deviation from the general fire behavior in such mines, the occurrence of fires of various origins throughout the years where documentation is available[2-25] illustrates the importance of incipient fire detection. That is, detection at the incipient stage of a fire, followed by warning and subsequent evacuation of personnel, minimizes exposure to buildup of toxic gases and smoke likely to obscure vision and prolong egress. The release rates of products of combustion and thermal energy cover a very wide range of problems between two limiting cases: (a) ignited or open fire (slow to rapid temperature versus time histories) due to ignition of National Fire Protection Association (NFPA) Class A-C† fuels in production or transport areas and (b) spontaneous combustion in larger unattended regions (weeks to several months or even longer). Rapid release rates due to fuel/air ignitions or explosions in gassy or combustible ore mines, such as in sulfide ore bodies, are excluded from the present study since they are receiving

*Coal mines come under separate health and safety studies and, therefore, are not considered herein as non-metal mines.

#Work performed under Bureau of Mines Contract No. S 0144131.

†*Class A:* Ordinary combustible materials (wood linings, timber supports, ventilation supports, packaging materials, conveyor belts, polyurethane, polyvinylchloride, etc., and, in a loose sense, combustible ores, shales, and explosives).

Class B: Flammable or combustible liquids, gases, and greases; for example, petroleum fuels, lubricating oils, hydraulic brake fluids, and combustible mine gases.

Class C: Electrical equipment; for example, overheating of polyethylene insulated (neoprene coated) power line cord.

considerable long-range attention in related areas involving expanding flames via methane-air ignitions and coal dust-air explosions.[26]

Properly used and reliable fire sensors, categorized as direct contact, optical view field, and products of combustion, are highly desirable from a property protection viewpoint in metal and non-metal mines. Questions arise concerning proper use and reliability of state-of-the-art sensors, which were developed for normal industrial or residential use and military or commercial aviation fire protection, in mines. Proper use includes not only selection of the appropriate sensor(s) for the area to be protected but also critical review of minimum detector spacing and positioning. Detailed protection methodology based on NFPA standards for the various sensors in industrial and residential use is inapplicable from simple cost considerations; e.g., a typical large mine may have 300 miles of tunnels. High-risk areas such as rubber conveyor belts for haulage,[27] large diesel-powered trucks,[28,29] and the working face (drill-vein interface) in coal mines[30] are examples of proper protection.

The reliability aspects of the more sensitive optical-view field and products-of-combustion detectors must be subjected to even more critical evaluation in mines since these sensors are prone to false alarming in industrial and residential use.[31] Thus, mine environmental extremes, such as (a) temperatures—subzero °F, depending on mine location and tunnel elevation, to 100° F or even higher; (b) from dry air to 100% relative humidity resembling a dense fog or mist; (c) high air velocities—up to 40 miles/hour in ventilation air intakes; and (d) pressure drops up to 12 in. H_2O across pressure doors on which diesel exhaust fumes, shot-firing gases, and normal mine gases can be superimposed, pose formidable obstacles on state-of-the-art sensors. Simultaneously sensing CO, CO_2, NO_x*, and O_2 gaseous species affords possible techniques to circumvent these complexities. Carbon monoxide sensing, in particular, is viewed as a reliable method for detecting cellulosic and hydrocarbon fires. For spontaneous combustion, at least in coal mines, the ratio of carbon monoxide concentration to oxygen deficiency may be a reliable fire detection criterion. Under certain conditions air ventilation networks can enhance sensitivity and effectiveness. Sampling tube networks or remote *in situ* detectors also appear useful for monitoring of several locations individually.

In spite of these complexities certain detectors appear applicable in protecting specific regions while meeting the aforementioned ambient fluctuations and aerosol or particulate contaminant insensitivity. For example, direct contact detectors based on heat detection principles—such as fixed-temperature and rate-compensated devices—would appear to provide adequate protection of NFPA Class B fuel storage areas. Alternatively, these devices would not respond to smoldering fires having low heat release rates. The successful demonstration of an infrared/heat sensor system for large diesel trucks[28,29] appears directly applicable to NFPA Class B fuel storage areas.

These aspects of mine fire detection will be considered in greater detail in the following subsections because of their importance to the detection problem.

*Pertains to total oxides of nitrogen, primarily NO and NO_2. At flame temperatures NO_x is essentially entirely NO.

pendent experimental methods.

BACKGROUND AND DISCUSSION

Metal and Non-Metal Mine Fire Data

Detailed fire statistics similar to those compiled for coal mines (for the past 20 years an average of roughly 50 major fires resulting in an average fatality rate of 4 per year in U.S. coal mines[32,33]) are apparently not available for domestic or foreign metal and non-metal mines.[34] Nevertheless, the comprehensive report by Harrington in 1933[4], Bureau of Mines reports,[2-25] and recent detailed contractor reports[35,36] provide adequate information for assessing fire types, potential causes, and fire detection effectiveness in these widely varying situations.

Harrington's report not only presents detailed fire statistics but also various important mine operating and fire control procedures, many of which are applicable today. Although it is reported that in 90% of metal mine fires there was no loss to life, heavy losses occurred in property. Other important aspects of this report may be paraphrased as follows:

1. Timbered stopes back-filled with waste-rock material containing considerable percentages of finely divided copper or iron sulfides when ignited constitute a most difficult fire.
2. Careless practices in leaving chips or shavings of timbers, excelsior, sawdust, oily waste, old clothing, and other combustible refuse in abandoned workings have resulted in starting or aiding destructive fire growths.
3. A large proportion of fires in metal mines originate at or near shafts. Intake-air shafts are generally dry, and if timbered, constitute a fire hazard. Downcast shafts should be concrete, and if that is not feasible, timbered shafts and shaft stations should be fireproofed. Since many fires in timbered shafts are started by electrical short circuits, it is desirable where feasible to transmit electric power underground through drill holes.
4. Water lines at least 2 in. in diameter should be available with suitable surface storage and valve control, not only in shafts and shaft stations but also on important levels.
5. There should be at least two openings through which one may escape without danger or difficulty; if the mine is deep (say, 500 feet or over) and employs a considerable number of men (say, 25 or more underground on one shift), two shafts should be available, each with hoisting equipment capable of removing the men from the lowest levels with minimum delay.
6. Probably the best and most effective method of life and property protection in the event of a fire is through use of a properly controlled and maintained ventilation system having (a) air-tight doors so placed as to be able to isolate shafts from mine levels; (b) air splits held absolutely separate from each other and hence able to confine smoke to but a small part of the mine; and (c) the main travelway downcast or on the intake, thus allowing escape in fresh air unless the fire is in the main travelway.
7. Fans should have reversing features if main shafts or travelways are upcast.
8. Properly supplied refuge chambers with air-tight doors are suggested for

mines with bad fire hazards or should be required for mines with only one opening to the surface.

Observation of these recommendations of Harrington would appear to have been sufficient for preventing the major Sunshine disaster. Riley[37] points out that air from the main fans fed the fire in a worked-out and abandoned area of the mine and forced toxic gases and smoke through abandoned raises to two major haulage levels, contaminating the main intake airstreams. Smoke then followed the normal air path into the work areas, then back up through the active stopes to the exhaust airway, forming in effect a closed circuit.

Since September 16, 1966, the effective date of the Metal and Non-metallic Mine Safety Act, 33 recorded fires resulted in a total of 114 deaths.[37] These fires involved nearly every type of fuel and circumstance. Actually, at the Sunshine Mine alone, prior to their major disaster, several fires occurred—involving a conveyor belt, cable reel machine, battery-powered locomotive, and two transformers; fortunately, no fatalities occurred.

Data[2,4–25] show a fairly high percentage of fires of electrical origin. Thus, it is important to examine detection of such types of fires in laboratory studies. Likewise, solid fuels such as wood, selected plastics such as fire retarded polyurethane foam*, various sulfide ores in conjunction with cellulosic combustibles, selected liquid fuels such as lubricating oils, and brake fluids also merit attention.

The compendium of Greuer,[35] with 147 references, contains a detailed accounting of the influence of mine fires on the ventilation of underground mines and is thus an important source of fire detection information, such as rates of fire growth and extent of contamination of ducts. Some of the important highlights are given in the following paragraphs.

The greatest hazards of mine fires are caused by

1. Toxic and sometimes explosive products of combustion carried by the ventilation system through the mine and

2. Unexpected airflow reversals carrying toxic fumes to intake air ventilation areas such as fire escape routes and hoist areas—i.e., areas generally considered safe in event of a fire.

Mine fires may be of two distinctly different types—overventilated or underventilated, i.e., oxygen-rich or fuel-rich. Parameters that influence these types are the chemical nature of the fuel, fuel loading, ignition source, and airflow rate or fuel to air ratio in "classical" combustion terminology. For timber fires, the fuel-rich fire type represents an extreme toxicity hazard because of the very low O_2 concentrations (16% O_2 is the minimum required to sustain life over short time periods) and high CO and CO_2 concentrations. In comparison with fuel-lean conditions, the amount of smoke given off for fuel-rich conditions is also greater; thus, egress times are prolonged because obscured vision and toxic species exposure correspondingly increases. Polyurethane foam seems to represent an extreme hazard, not only since its mass rate of fuel evolution per area is roughly triple that

*Flame-retarded polyurethane will burn at a slower rate and produce denser smoke than the non-retarded variety; additional toxic species can result from the degradation of the flame retardants.

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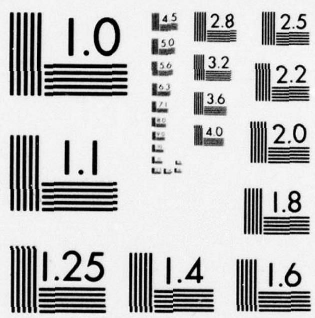

MICROCOPY RESOLUTION TEST CHART
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of timber, but also since its products of combustion are more toxic (LTV* of HCN and CO are 10 ppm and 50 ppm, respectively) and emit denser smoke.[38,39]

The analytical prediction of airflow reversal in a mine, even with idealized geometry, is an extremely difficult task. Greuer[35] expends considerable effort examining various aspects involved in reversing ventilation airflows. For the three types of airways, horizontal and ascensionally and descensionally ventilated, the following important qualitative predictions warrant mention:

1. Horizontal airways—Open fires with only negligible temperature changes in following non-horizontal airways produce a throttling effect that produces an airflow decrease in the airway and all airways in series with it. Airflow reversal cannot occur in the airway and the series airways. It is possible to reverse airflow in diagonal airways that connect parallel airways.
2. Ascensionally ventilated airways—Natural convection will generally be stronger than throttling effect and increase airflow for at least moderate temperature differences and elevations and not too large air flows. The increased airflow is accompanied by a decrease in parallel airways. For small ventilation pressures in these airways, airflow standstills and reversals can occur with known dangerous effects.
3. Descensionally ventilated airways—Natural convection for a sufficient driving force decreases or can even reverse the original ventilation flow, even though they are opposed in direction. Violent fluctuations in air flow are expected during fire.

For an actual mine under operating conditions, it appears impossible to predict the occurrences and paths of air flow reversal(s) within the time scales necessary for rapid mine evacuation. The need for reliable fire sensors is once again evident.

Metal and Non-Metal Mine Environments

Typical mine environmental extremes in temperature, humidity, and air velocity, in addition to background aerosol signatures due to diesel exhaust fumes and shot-firing gases, were mentioned earlier. Discrimination against these normal mine ambient parameters appears important in the design of reliable fire detection systems. The analysis of non-coal-mine atmospheres by Mine Safety Appliances (MSA) Research Corporation under a Bureau of Mines contract[40] provided CO, CO_2, condensation nuclei, NO_x (also NO breakdown), and SO_2 concentration data for shot-firing and diesel operations for selected mines and sampling sites. The high particulate concentrations expressed in terms of condensation nuclei are comparable to an actual fire situation. Photoelectric products-of-combustion detectors sensitive to visible particulates would seem to be less sensitive to these operations. However, it must be emphasized that the visible particle fraction was not determined, and since shot firing and diesel operations are known to give off visible smokes, it is probable that photoelectric sensors will give false alarms during these operations.

The measurement and control of diesel emissions is a subject of much concern

*Lower threshold value; time-weighted average concentrations for an 8-hour period.

to Bureau of Mines personnel.[41,42] Under typical conditions, 1 pound of fuel produces approximately 200 ft^3 of exhaust gas, which is comprised roughly of 20 ft^3 CO_2, 1/3 ft^3 CO, 1/3 ft^3 NO_x, with the remainder N_2 and H_2O vapor. Methods for control of diesel smoke; CO, total hydrocarbons, and odor; and NO_x are presently available and either have been or are being incorporated into today's diesel equipment. Carbon dioxide, however, cannot be controlled. It is directly and linearly dependent on the amount of fuel burned and is an important indicator of residual exhaust contamination. It is interesting to examine the low concentration range data[41,42] for which the ratio of CO/CO_2 is constant. For typical operations the ratio CO/CO_2 is approximately 1/50 to 1/125. The value 1/50 is surprisingly close to the mean of the CO/CO_2 values obtained by MSA.[40] One reason for not approaching the 1/125 ratio is apparently the more complete combustion conditions in testing[41,42] whereas in the actual mine environment more complete combustion would seem difficult to attain. Although discrimination against diesel exhaust and shot-firing operations based on differences in the ratio of CO/CO_2 initially appeared promising, recent in-mine sampling data (see Table 1) show only slight differences in the CO/CO_2 values for these operations versus actual fires.[43] The concept of gas-sensing the ratio of two species nevertheless remains valid for CO/NO_x and CO_2/NO_x as shown in Table 1.

To obtain actual fire detector performance information in a mine, battery-powered ionization detectors were taken below ground by Gillette Research Institute investigators.[44] Performance behavior may be summarized as follows:

1. Statitrol-Smokeguard I was unsatisfactory on an overall basis in the Bunker Hill Mine, Kellogg, Idaho, primarily in areas contaminated with high concentrations of aerosols and in regions of high ventilation air flows. Satisfactory performance was obtained in regions supplied by low-velocity intake air.

2. BRK Electronics Model SS74R (a dual-gate type of ionization detector) performed reliably in Central Rock Company (CRC), Lexington, Kentucky. It should not be inferred that the BRK detector is superior to the Statitrol unit, since the Bunker Hill mine presented far greater environmental extremes than the CRC mine. Both BRK and Statitrol ionization detectors gave false alarms in close proximity to a diesel engine at the Minerva mines in Cave-in-Rock, Illinois.

TABLE 1

Gas Concentration Ratios for Various Mine Operations[43]

Operation	CO/CO_2	CO/NO_x	CO_2/NO_x
Blasting	0.1-0.7	3-14	4-24
Diesel	0.05-0.1	7-10	85-95
Leaky bulkhead	0.05	10	3,000
Fire (return air)	0.04	300	70,000
Fire (sealed bulkhead)	0.02	1,650	80,000

Since this poor performance was obtained after just a few hours in these mines, it appears unlikely that the ionization detector can perform satisfactorily in active mine areas for periods of even a few months.

DETECTOR ENVIRONMENTAL CONSIDERATIONS

The state of the art of fire detection devices (conventional and non-conventional types) and gas sensors is surveyed in this section. In certain cases there is overlap between the classification schemes, since certain types of fire detection devices are gas sensors, and sensors detecting gases such as CO, CO_2, and NO_x may be loosely interpreted as non-conventional products of combustion-type fire detectors. In various aspects this review reflects earlier studies;[45,46] however, recent pertinent information obtained from literature searches and fire detection study programs updates these earlier works. The fire and normal mine environment detailed earlier is again considered here, emphasizing fire detection concepts.

The objectives of this review section are to examine the operational characteristics of fire and gas detection devices under different test conditions and to outline potential areas of mine applicability and likely problem areas. Furthermore, promising detector hybrids and modifications to existing devices that could minimize some of the mine environmental extremes and thereby extend the useful life of sensitive detectors in a mine are also considered. This is done within the framework of detector reliability, reasonable cost, compatibility with regulations and requirements, and fire suppression methods.

Fire Detector Reliability

The present status of the reliability of fire detectors obtained in industrial and residential embodiments up to 1970 is illustrated by the Joint Fire Research Organization (JFRO) data in Tables 2 and 3, which show very high false alarm ratios—the average being 11:1.

TABLE 2

Summary of Calls Received

Type of System	Number of fire calls by system installed	Number of false calls	Ratio of false calls to fire calls
All types	489	5,441	11.1:1
Heat	193	2,146	11.1:1
Smoke	101	1,429	14.1:1
Heat and smoke	18	410	22.8:1
Sprinkler	101	1,048	10.4:1
Manual	55	243	4.4:1
Mixed	18	137	7.6:1
Unspecified	3	27	9.0:1

Note: The total number of false calls includes one false call from gas detector equipment.

TABLE 3

Reasons for False Calls

Reason	Totals (all types of equipment)	
	Number	Percentage
Total (all reasons)	5,441	100
Ambient conditions	1,410	26
Mechanical and electrical	2,507	46
Communication	901	17
Unspecified and unknown	623	11

In the extreme environment of aircraft engine nacelles of USAF aircraft, 83% of all reported alarms were false in a study that covered 1250 total alarm cases with 1036 false alarms from 1965-70.[47] It was also found that in roughly 50% of the engine nacelle fires, where detection system performance could be determined, the system did not alarm at all. The detection systems were primarily direct-contact thermal sensors involving continuous overheat line and thermocouple sensors of several different commercial vendor types. By utilizing an integrated systems approach involving four pairs of fire sensors in each nacelle, with ultraviolet and infrared sensors in each pair and a dual-loop overheat sensor coupled with computer control for signal processing and crew warning, false alarms are expected to be eliminated.[48] The important detection criterion here requires that two sensors with the same optical field of view must indicate the existence of a fire before a fire warning is signalled to crew readout. Actual tests results are not yet available. Such an approach is certainly applicable in a mine in areas where fuels that undergo flaming combustion are stored.

One might expect higher false alarm ratios in the mine environment than those obtained in the JFRO study because of far greater adverse ambient conditions, as well as mechanical, electrical, and communications difficulties therein. Such a tendency has already been observed for the ionization detector (page 71). Utilization of an integrated or hybrid system concept does not follow as readily as for the engine nacelle fire since mine fires include types from spontaneous combustion to flash fires. For example, we wish to protect an area from a potentially slowly developing fire expected to give off large quantities of smoke, coupling, say, an ionization or photoelectric detector with a fixed temperature/rate of rise thermal sensor by requiring an alarm for both sensors. It is possible that this would not lead to alarm or alarm at a very late stage when the fire is already out of control because of the delayed response of the thermal sensor. This hypothetical example seems realistic, especially if the heated combustion products are diluted with cool inlet ventilation air. The integrated concept appears applicable only when one couples different detectors of similar time responses.

Detector companies state that improper maintenance is an important factor

contributing to the 46% mechanical and electrical failure rate[49] in Table 2. However, possible cleaning procedures, such as removal of dust or adsorbed combustion products from electrode plates of ionization detectors by disassembling the detector head, or inserting a new detector followed by cleaning of the used detector above ground appear to pose a heavy burden on effective maintenance in environmentally extreme regions of the mine. Other problem areas come to mind that will be discussed under the behavior of the various detector types.

Since it is recognized that there is no universally applicable fire detector, i.e., one that responds accurately and uniformly to all types of fires, the various detector types will each have certain advantages and disadvantages. Trade-offs in detector characteristics are also common, e.g., increased sensitivity to a lower threshold level of combustion product versus an increase in the integrated time for detection.

It is interesting to note that there is no published long-term information (say, a year or so) on detector sensitivity under conceivable extremes of ambient conditions, such as high relative humidity, vibration, concentration fluctuations from diesel exhausts, shot-firing gases, high concentration of dusts, and oily or corrosive vapors. Such information is vital to the detection problem in mines.

One way of summarizing our feelings about mine fire detector installation(s) is to state that unreliable fire detectors should *not* be installed in mines. This follows from numerous verbal disclosures pertaining to industrial fire detection where frequent false alarming led to turning the detection system off while not notifying the proper personnel, followed by the fire scenario. Documentation is available for aircraft where fire detection systems were partially or totally removed to reduce or eliminate false alarming.[47] Applying this form of thinking to the mine problem, it is concluded that considerable harm or damage to life and property could result if a miner is operating under a false sense of security. An actual fire not followed by alarm, even though smoke is detected by the senses, could be ignored since it was conjectured to be due to normal mine blasting or diesel operations.

Fire Environment/Detector System Design

To design an effective fire detection system, one needs to assess available information on at least the following factors:

1. Fire itself—Need to know the relationship between the fuel (NFPA Classes A-C) and surroundings. The type, amount, arrangement, and heat release rate, as well as the nature, size, and ventilation patterns of the enclosure enter into the picture.
2. Mine environment—Specified previously.
3. Damageability of area and life hazard—Areas in the mine that represent high risks to personnel and property would require increased numbers of detectors per given area versus low risk areas. High-risk areas would seem to include fuel storage depots, regions at or near shafts, and abandoned or worked-out areas containing combustibles capable of undergoing spontaneous combustion.
4. Response time of the agent that puts out the fire and application mode—Halon 1301, AFFF, high-expansion foams, chemical foams alone or with dry

powder, manual or automatically actuated system, or crash truck system. Temperature-time histories for Class A-C fuels encompass very slow conditions (spontaneous combustion orders of weeks or months or even longer) to very rapid (essentially instantaneous, i.e., order of milliseconds such as ignition of methane-air or dust-air mixtures).[26]

Major problem areas besides the effects of fire on ventilation or vice versa and mine environment on detector integrity would also appear to include system installation ease, portability, and ruggedness and adaptability to another location differing in size, geometry, ventilation patterns, and ambient environment. As active areas of the mine are worked out, combustibles necessary to sustain normal operations are often moved closer to the new active area in order to operate efficiently. These problems imposed by system portability are of course not inherent to fixed installations.

Aerosol and Gaseous Fire Signatures

Characteristics common to mine fires of primary concern are the generation of aerosols and release of gaseous combustion products, notably CO, CO_2, and NO_x. Aerosols cover a particle size range of from 5×10^{-3} μm (values down to 10^{-3} are doubtful) up to 50 μm. Heating materials first produce submicrometer particulates around 10^{-3} μm, with particle sizes ranging from 0.01-1 μm around ignition temperatures. A particle size of 0.3 μm is the dividing point between invisible and visible particles, i.e., particles less than 0.3 μm do not scatter light very well and are thus classified as invisible, whereas particles greater than 0.3 μm do scatter light and are classified as visible. The size range of 0.01-1 μm covers smokes; an upper range of 5 μm is given in one reference[50] for smokes. Smokes are defined here as low vapor pressure particulates that settle slowly under gravity. In the upper aerosol size range, mists are also given off during the combustion process. Mists are liquid droplets that can be formed by condensation of vapor following cooling of heated fire gases, e.g., via turbulent heat and mass transfer exchange with cold ambient air.

The generation of smoke or its dependence on specific physiochemical parameters has not been rigorously determined for fire-related problems. The problem of particle aging as it pertains to fire detector response also comes to mind. Nevertheless, fundamental information derived from air pollution studies[50-56] is applicable in limited regions.

One of the main characteristics of particulate clouds is their instability. Particles may grow by coagulation or by vapor condensation on smaller nuclei. They may disappear by evaporation, sedimentation, or diffusion to confining walls of enclosures. If a certain fraction of the heterogeneous mixture is charged unipolarly then increased stability almost comparable to hydrosols can be obtained. Another complication can arise from aerosol formation by the mixing of vapor-laden gas streams at different temperatures, e.g., a clean-burning fuel giving rise to a free convective turbulent plume that entrains cold atmospheric air. The phenomenon of thermally induced stratification of smoke can adversely influence particle movement. For example, a thermal gradient beneath a ceiling can prevent smoke

from penetrating the ceiling's thermal boundary layer. Kennedy[57] points out that a vertical temperature gradient of only approximately 5°C in 100 feet was sufficient to stratify cold smoke at the 75-foot level. There is every indication that this phenomenon can occur at much smaller heights since thermal stratification was actually an early technique used in aerosol studies for particle sizing.[58]

Another important characteristic of particulate clouds is their ability to scatter, reflect, and absorb radiation to a degree depending on their size, color, shape, and the wavelength of incident radiation. Mie theory describes the scattering of radiation by optically isotropic spheres, i.e., non-absorbing substances. The commonly used Lambert-Beer law, also frequently referred to as Bouguer's law, is used to describe the absorption of radiation as a function of absorbency index, concentration, and path length.

Considerable practical information on smoke produced from burning of various materials exists.[39,59] The important findings on over 100 different materials under a 2.5 W/cm^2 radiant heat flux exposure[39] may be paraphrased as follows:

1. Woods, including solid woods, plywood, and other cellulosics show specific optical density versus exposure time variations similar to those for red oak in flaming and non-flaming exposures, both with and without ventilation. Fire-retardant treatments produced denser smokes under flaming conditions.

2. Plastics may be divided into two broad categories: (a) those that produce no visible smoke under either flaming or non-flaming exposure (few in number); and (b) smoke producers (the vast majority) subdivided further as those that behave similarly to wood, slowly building up to a high density, or those that build up fairly rapidly but to about the same density.

3. In the presence of heat and flame two separate phenomena were observed: (a) plastics that tend to burn cleanly are similar to wood under similar conditions and (b) those that do not burn cleanly, i.e., are fire-retarded, rapidly evolve dense to very dense smokes not readily cleared away by ventilating.

In mines, likely sources of dense smokes include at least the following: synthetics or plastics materials such as polyurethane and various packaging materials, clothing items, flame-retarded conveyor belts, electrical insulation, lubricating oils and greases, petroleum fuels (increased smoke density with an increase in aromaticity and higher molecular weight straight chain hydrocarbons), hydraulic brake fluids, and shales. Cellulosic fuels such as wood linings, timber supports, and cardboard boxes and mine gases such as CH_4 would seem to comprise the more important fuels of lower density smokes. Wood age and moisture content would be important variables in this classification scheme. In addition, mine dust, its color and concentration, would also appear to be of importance.

For combustion of various other mine materials, other gaseous species besides CO and CO_2 may include at least lower molecular weight hydrocarbons, NO_x, NH_3, HCl, HCN, HF, and H_2S.[38,60] With the exception of certain plastics known to yield high concentrations of these gases, e.g., PVC, which yields roughly 50% by weight of HCl upon heating to temperatures in excess of 300°C,[61] designing fuel-specific detectors offers limited applicability. For example, PVC pyrolysis

and/or combustion produces copious quantities of smoke and thus this signature can be detected by conventional means.

The gases of importance appear to be CO, CO_2, and NO_x, combined with O_2 deficiency. The ratio of CO to O_2 deficiency appears to be a reliable parameter to follow the onset of spontaneous combustion in coal mines. Oxygen deficiency is also the result of fuel-rich burning; CO and CO_2 need no further amplification here. Nitrogen oxides are important only because they are a product of high-temperature combustion, such as in a deflagration wave in diesel engines and controlled mine blasting or explosion operations. Under fire conditions most naturally occurring and synthetic materials, excluding those with high nitrogen content such as polyurethane and the acrylonitriles,[62] will not produce the temperatures for high NO concentrations. Thus, sensing NO_x appears to afford a means for discriminating against ambient diesel and blasting signatures, which have all the characteristics of an actual fire.

Sensing CO, CO_2, or the ratio of CO/CO_2 as an indicator of a fire requires comment. Presently, it appears that sensing CO or CO_2 separately is limited to a hybrid system, i.e., one used in conjunction with other existing detectors, whereas sensing CO/CO_2 may be unreliable as explained in paragraph 4 below.

1. The lower threshold value (LTV) based on an 8-hour exposure to CO is 50 ppm; thus, certain types of fires may go undetected if the CO detector is of a low-sensitivity type. The lower limit of CO will be determined by the type of sensor and its environment.
2. Employing a CO detector that responds at, say, half the LTV value or 25 ppm would seem to be prone to false alarming. Nearness to a source of products of combustion such as diesel exhaust or shot-firing gases would seem to promote unwanted false alarms. Alternatively, formulation of a detection principle based on alarm only after continuous sensing of a predetermined CO level for orders of tens of seconds would seem dangerous, since rapidly developing fires might get out of control.
3. CO_2 is a product of complete combustion and human exhalation and thus could be unduly high in certain areas, indicating fire conditions.
4. The ratio of CO/CO_2 for idealized burning of various fuels is well known to be in the ratio 1:2. However, combustion processes in mines are rarely ideal. More recent MSA sampling data (see Table 1) for CO/CO_2 ratios that differ by only factors of 1.25 to 5 for diesel and actual mine fires leave limited room for error in use of this approach.

Table 1 data for CO/NO_x and CO_2/NO_x nevertheless show that values for these ratios may be used to discriminate blasting and diesel operations from mine fires. If CO or CO_2 sensing were to be used for fire sensing because of the high cost of NO_x monitors and the availability of various sensitive CO and CO_2 monitors,[63,64] then false alarming will have to be an accepted consequence. Because of the complexity of sensitive NO_x, CO, and CO_2 monitors, which require highly skilled maintenance, such hardware is recommended only for use in a multipoint gas analysis system.

OPERATIONAL CHARACTERISTICS OF CONVENTIONAL AND NON-CONVENTIONAL FIRE DETECTORS AND GAS SENSORS

The categorization of the various sensors into three classes—direct contact, optical view field, and products of combustion—requires clarification, since even conventional fire detector devices have back-up features and respond to more than one parameter. For example, ionization-type products-of-combustion (POC) detectors are sometimes equipped with back-up heat detectors; similar features are also available with photoelectric detectors of visible smoke. For these hybrid types, classification will be according to the primary intended use. For non-conventional fire detectors, many of which have applicability in gas analysis or are outgrowths of gas chromatography, and gas sensors, classification is not that direct, as previously pointed out. A few examples are offered for clarification purposes. Thermal conductivity detectors, which are classified as filament-type detectors in conventional gas sensor terminology, will come under POC detectors since the application is to employ differences in thermal conductivity between fire and ambient background as a criterion for the presence of a fire. Non-dispersive infrared analyzers for the important fire gases CO and CO_2, which usually come under optical methods, will come under products-of-combustion sensors. Although not necessarily the best scheme, classification in such a manner is required, since it maintains self-consistency and minimizes the numerous possible classified schemes. The detector types may be further divided into the point source, spot, or local type, depending on preferred terminology (i.e., one actuated by a combustion product or heat brought to the detector by free or forced convective heat and mass transfer mechanisms) or the extended area type.

Information on the different types of fire detectors is now available in comprehensive survey articles,[45,46,65,66] NFPA reference books,[67,68] recently proposed standards,[69] and corporate sales brochures. Excellent detailed information on gas sensors exists in the monograph of Verdin[64] and recent translations of Russian texts and articles.[70–72] Custer and Bright,[66] besides including much of the technical information from other sources,[45,46,65,67,68] also give important discussions of U.S. and foreign performance standards and acceptance criteria for detection devices.

The specific operating characteristics discussed in the sections that follow are based primarily on the updating of Wagner's work,[45,46] from information derived from computer searches of the literature conducted through National Technical Information Service (NTIS), Smithsonian Data Bank, Chemical Abstracts, surveys of open literature, and existing detector programs.

Direct Contact

Direct contact detectors, or heat sensors, are of two general types: those employing the fixed-temperature principle and those employing the rate of rise principle.[67] In the fixed-temperature approach, an ideal temperature level is first selected, say, $131 \pm 5°F$. When the active element is completely heated to its operating temperature the heat-sensitive material will bend, expand rapidly, fuse, or produce a current that can be used to actuate an alarm. Commercial devices include

ampoules, bimetallic elements, eutectic solders or salts, snap discs, thermocouples, thermistors, continuous line types (thermistor, eutectic salt, or twisted cable under tension), fusible plastic types, and certain photoconductors. Major disadvantages, except for rapid-response thermocouples, include slow response times because of built-in thermal inertia and inability to detect certain slow smoldering fires. Response times for commercial fire detector thermocouples are around a few tenths of a second. Primary advantages are low cost, reliability, freedom from maintenance, and insensitivity to vibration and dust-laden atmosphere.

Suppliers of continuous line heat sensors are Fenwal, Walter Kidde, and Protectowire Company. The sensing element in the Fenwal system is an Inconel tube packed with a thermally sensitive eutectic salt and a nickel wire center conductor.[73] When a fire situation occurs at any point along the entire element length, the resistance of the salt drops sharply, thus producing increased current. This current is sensed by a control unit, which produces an output signal to actuate an alarm. The Kidde sensing element contains a ceramic-like thermistor material in which are embedded electrical conductors, also housed within an Inconel Sheath. Electrically the element behaves as an infinite number of unit thermistors connected in parallel along its entire length.[74] The response to fire is to the sum of resistances (in parallel), which reflects a non-arithmetic average. Both units reset themselves upon removal of the fire condition and are rugged enough to withstand severe vibration and shock. A disadvantage is that the lowest sensing temperature of the presently available salts is around 250° F.

The Protectowire line detector is comprised of two twisted high-tensile spring steel wire actuators, each individually encased in a thermoplastic or heat-sensitive material.[75] This is spirally wrapped with a protective tape and provided with an outer covering. Upon heating any point along its length to alarm temperature, the plastic yields under its applied tension, causing the actuators to move into contact with each other. The electrical connections consist of a series connection of a power source, a supervisory relay, and a resistor connected to the end of the wire actuators, so that a small current continuously flows through the system. A break in an actuator or loss of power triggers the supervisory relay, and it produces a trouble signal from a second power source. Other system arrangements are possible. Following a fire the heated part of the line will look swollen and must be cut out and a new piece spliced in using splicing sleeves. The lowest operating temperature is 155° F, which appears ideal for mine use. However, while Protectowire is resistant to moisture, chemical fumes, and other deteriorants, the standard type is not intended for use in the presence of extreme moisture or other deleterious service conditions. However, a waterproofed version is presently available and should prove adequate in the generally moist metal and non-metal mine atmospheres.

A heat-sensing transmission line has been proposed as a possible method of protecting automatic warehouses from fire.[76] It operates on the principle that an electrical pulse traveling down the line must sense a discontinuity in the characteristic impedance of the line due to the fire. The line requires characteristics that change rapidly with temperature in order to minimize response time. Experimental results are needed on the parameters associated with fire-damaged transmission lines before this device can be put into operation.

Rate-of-rise detectors are designed to respond to changes in temperature at a rate of around 15°F/min. They are fairly reliable and will not alarm for slow increases in ambient temperature. They are not suitable for smoldering type fires and also where rapid temperature changes occur naturally, such as near mine ventilation doors connecting tunnels or passageways of widely varying temperatures. Two fairly common rate-of-rise detectors are the pneumatic tube detector, which affords extended area protection, and an orifice-type detector. In the former device, a pressure buildup in a detector diaphragm chamber is used to close a set of contact points at some predetermined value of pressure.[65,67] The latter device relies on pressure increases resulting from differences in flow rates of an expanding gas passing through an orifice.[77] Here sensitivity is directly related to orifice size.

Rate-compensated devices of Fenwal and Notifier Corporation combine the fixed temperature principle with the rate of rise.[78,79] The key requirements are materials of different coefficients of expansion. For very low rates of rise, both materials expand uniformly and the device operates as a fixed-temperature device. For rapid rates of rise the materials no longer expand uniformly, which leads to an alarm even though the fixed temperature is not reached. This device also is not capable of detecting slow smoldering fires.

Our assessment of contact detector applicability in mines is as follows: Applicability is limited to regions where slow smoldering fires are unlikely and the preceding ambient criteria are satisfied and in regions where products of combustion such as from diesel exhausts could lead to high false-alarm ratios for sensitive combustion-product detectors. The distance from the diesel combustion source to the detector is important, since mixing of heated exhaust products with cooler ambient air is necessary so that the temperature of the air parcel reaching the sensor does not exceed its alarm temperature. Alternatively, diluting heated fire gases with cooler ventilation air should not be so great as to prevent an alarm from small flaming combustion sources. Proper detector spacing is viewed as one way to design against this unwanted behavior.

Optical View-Field

Fire detection devices under this category respond to radiant energy in the ultraviolet and infrared portions of the electromagnetic spectrum generated during flaming combustion of materials. Many problem areas exist for these devices, as illustrated by their high frequency of false alarming (Tables 2 and 3) and their rather high cost. Principle sensing elements include solid-state detectors, tubes (vacuum or gas-filled), and thermocouples or thermistors for specialized application. A summary of the operational principles of photodetectors—photoemissive, photovoltaic, photoconductive junction type, and photoconductive bulk effects—is given elsewhere.[45] Of particular interest in the fire detector field are the photovoltaic devices, which presently often require some degree of amplification. One might expect future devices to respond to fires in a manner similar to the RCA light-sensitive monolithic integrated circuit (page 21 of Rf. 80).

For the infrared detector, background radiation at ambient temperatures from walls (25°C) and people is entirely in the infrared region (wavelengths greater than

roughly 8000 Å). Discrimination against background is frequently handled by chopping the incident radiant flux so that the detector receives only a fixed radiant frequency, typically 4-30 Hz. One version of an infrared fire detector employs a system of optical and electronic filters that limits detection to a narrow signal wavelength of range 1-2.75 μm and frequency of 4-15 Hz.[81] The infrascan detector described in this reference has a scanning reflector that rotates at 6 rpm. When infrared radiation of the proper characteristic is reflected from it onto a sensitive cell for an uninterrupted period of 15 seconds, an alarm will sound. The radius of scan is up to 400 feet through 360° horizontally. Infrastat, a variation of Infrascan, does not employ a scanner. It is similar to a camera. A photocell is mounted inside a collimating tube protected by a quartz shield. By adjusting this tube, one can vary the angle of the cone of detection from 15° to 160°. Fires outside of this cone of detection will go undetected.

Pyrotector's near-infrared flame detector (discriminating) responds in the spectral range of 6500 to 8500 Å. The detection cell is a dual-element photoresistive solid-state device with appropriate optical filters.[82] The discrimination portion responds to approximately 4000 to 5500 Å. The two elements function as a spectral voltage divider to detect flame and discriminate against ambient light such as from sunlight and incandescent and fluorescent lighting. Its quoted sensitivity is 20 ft to 1 ft^2 of hydrocarbon fire at 10 ft-candle ambient light level (higher ambient light levels decrease its sensitivity); its cone of vision is 120°. It is recommended for use in low ambient light regions (such as in a mine) because of desensitization by high ambient light.

Infrared detectors are also classified broadly according to their response to heat and a photon flux:

1. Thermal detectors—Energy absorbed by a temperature-sensitive material or absorbing film in contact with the temperature-sensitive material; thermocouples, metals, or semiconducting layers with resistance a function of temperature (bolometer), pyroelectric detectors whose polarization is temperature-dependent, and gases with pressure (in a pneumatic cell) being temperature-dependent.
2. Quantum detectors—Photon flux incident on sensing element excites electrons in a bound state to a free or conducting state.

Another classification is to subdivide the infrared spectrum into three divisions according to the different detector types required for each area[83]:

1. Near-infrared—conventional Si and Ge detectors.
2. Intermediate—special infrared detectors.
3. Far-infrared (20 μm)—thermal detectors such as thermistors or thermocouples are required (see contact detectors).

PbS is one of the most versatile photoconductors that responds to infrared from approximately 1 to 4 μm. Intrinsic, i.e., undoped, Si and Ge detectors have limited near infrared response. However, doping with Hg and Cu extends the Ge operation up to 8 to 14 μm. Far-infrared detectors are generally of the bolometer (infrared heat detector for special applications) or thermocouple types.

Numerous detectors presently available require cooling. Generally, detectors with response up to around 3 μm and 180° field of view looking into ambient background (25°C) require little, if any, cooling.[84] Spectral response, speed of response, and the reciprocal of the noise equivalent power or detectivity, D*, provide further detector characterization. Here D* is the detectivity of a detector of a 1 cm^2 area whose noise is reduced to that obtained with an amplifier of 1 Hz bandwith.

$$D^* = \frac{S/N}{P_D}\left(\frac{\Delta f}{A}\right)^{1/2}$$

where S and N = signal and noise, respectively,

P_D = power density received by detector,

A = detector area, and

Δf = amplifier bandwith.

Sensitive areas vary from 0.01 mm^2 to 1 cm^2, with time constants shorter than 1 nsec. Lead sulfide, one of the earliest ir photon detectors, responds well to low wavelengths; InSb, however, is more useful since it covers the CO and CO_2 bands.[64] An ir detector selectively using the 4.4-μm CO_2 band in a Wheatstone bridge circuit is described by Hertzberg.[85]

The newer pyroelectric-type detectors consist of a slice of ferroelectric material (typically triglycine sulfate, tourmaline, Rochelle salt, barium titanate) and more recently polyvinylfluoride.[84,86,87] Electrically, the material behaves similarly to a capacitor with a strong temperature-dependent polarization of the magnetic domains. Small temperature increases caused by ir radiation through a transparent electrode produce a polarization charge on the pyroelectric material and a corresponding voltage change across the two electrodes of the sensing cell. Because of its high impedance, a field-effect transistor is utilized to lower the output impedance. Cohen *et al.*[86] describe use of a polyvinylfluoride sensing material in a scanning thermal setup for fire detection. Commercially available pyroelectric ir detectors of triglycine fluoroberyllate and triglycine sulfate require no cryogenic cooling and operate in ambient temperature ranges from -10°C to 60°C and -10°C to 40°C respectively.[88] With a standard window, i.e., KRS-5 (thallium bromide-thallium iodide), the spectral response is from 1 to 45 μm with a total sensitivity up to 500 μm. Because of its higher operating temperature, the fluoroberyllate would appear more useful than the sulfate for mine applicability.

The number of semiconductor uv detectors (wavelengths less than roughly 4000 Å) is very small compared to those operating in the ir region.[84] This is due to basic problems encountered in uv detection:

1. Conventional glass windows cut off below around 3000 Å and even quartz and uv-grade sapphire become opaque below 1800 Å.
2. Below around 1000 Å suitable uv windows are lacking. Detection in the intermediate or vacuum ultraviolet is generally accomplished by multiplier phototubes with photocathodes that are blind to wavelengths greater than 3000 Å.

The Honeywell basic uv detector Model No. C7037A, now acquired by Detector Electronics Corporation (Det Tronics Corp.),[89] designed to operate in the 1850-2450 Å region, is insensitive to both sunlight and artificial light. Its cone of vision is 90°. The quoted sensitivity is a 1 ft^2 flame from 15 ft. The sensing element is a gas-filled, uv-sensitive tube operating on the Geiger-Müller principle.

When an energetic photon in the uv spectral range strikes an appropriate cathode (tungsten is used in this device because it is not sensitive to the sun's radiation, etc.) and exceeds the work function of the cathode, an electron is emitted and is accelerated toward the anode (positive) plate. In passage through an ionizable gas toward the anode, the electron strikes gas molecules causing further electron emission. The total electron flow is typically several million times that of the single electron emitted from the cathode. This leads to an increase in current that may readily be measured. The detector is operated in a pulsed mode by allowing current to flow for a very short period of time before the voltage is reduced to stop the current. Amplification is thus required with this device.

Fenwal's uv detector[90] responds to uv radiation in the range 1900 to 2500 Å. It operates on the ionization principle similar to the Honeywell model. It has a 120° cone of vision. The response time given is 15 msec for a propane/air flame 1.75 in. high at a distance of 8 in. from the flame source.

Other suppliers include McGraw-Edison Company (range 2000-2750 Å)[91] and Pyrotector (1700-2900 Å, maximum response at approximately 2100 Å); these also operate on the Geiger-Müller principle. The latter device is particularly interesting, not only from its outward compact design appearance, but more importantly because it contains a solid-state ac-dc converter section to provide the necessary voltage for the detection tube and a signal integrator delay circuit (3 sec delay) to minimize false alarms from sparks, lightning, etc.[82] Its quoted head-on sensitivity is 6 ft to flame from a ¾-in. diameter candle.

Besides the normal problems associated with the inverse square law of radiant energy transmission, which include view factors, temperature differences, etc., as well as additional difficulties cited earlier, added factors due to moisture-laden environment resembling a fog or a mist would have to be assessed. This follows from the example that radiant energy propagation through a coal dust cloud (a strong absorber of radiant energy) could adversely affect fire detector response.[30] Also, contamination of the viewing window with oil film deposits would require attention. Because of the extreme mine environment, we have omitted a discussion of light-sensitive laboratory devices such as optical spectrometers or spectrophotometers, since they would not be expected to demonstrate reliability without continuous maintenance.

The likely area of applicability for infrared and ultraviolet detection is in protecting fuel storage areas, since these sensors are known to respond rapidly to flash fires.

Products of Combustion

Products of combustion in fires include solid particulates and liquid mists (including invisible and visible particle sizes), ionized species, gases, and radiant

energy. Combustion product detectors sense one or more of these constitutents, excluding heat or flame.

Alpha-Ray Ionization

This type of a detector employs a radioactive α emitter* (e.g., $Ra_2^{226}SO_4$, Am^{241}, etc.) to ionize air in a chamber between two electronic plates. Current in the 10^{-11} amp range results from production and transport of positive and negative ions to opposite poles of the plates. A decrease in the current, relative to air, is obtained when combustion products enter the chamber because of ion attachment to the lower mobility smoke particles and increased absorption and scattering of the α particles by the aerosol fraction of the gas. This decrease is monitored electronically, leading to the triggering of an alarm.

At high sensitivity settings, aerosols such as cigarette smoke, room deodorant sprays, and dust particles will trigger false alarms. Heat sensing thermocouples are recommended for use in conjunction with an ionization detector in order to circumvent this problem.[92] The ionization detector will also not function properly in regions where there is a high radiation background.[93] Alarm dependence on air flow velocity, particularly in ventilation duct works, is also reasonably well known. Questions concerning the ability to detect slow smoldering polyvinyl chloride (PVC) line cord degradation products at an early stage have also appeared and have now been confirmed by us.[94,95]

With the need for periodic cleaning of the detector plates cited previously, our performance evaluation in mines, and the factors mentioned here, we see limited applicability for the ionization detector in the mine environment.

Argon Ionization Detector#

This detector operates on the principle of ionization of foreign molecules by collision with high-energy Ar atoms leading to high concentrations of metastable Ar* of long half-life (10^{-4} sec)[96]:

$$Ar + \beta \xrightarrow{-15.7ev} Ar^+ + e$$
$$Ar^+ + e \xrightarrow{11.6ev} Ar^*$$
$$Ar^* + \text{Impurities} \rightarrow Ar + M^+ + e$$
$$Ar^* + \text{Combustion Gas} \rightarrow Ar + M^+ + e + \text{Signal}$$

Either β or α radiation in the 10 to 50-millicurie range placed in an electronic chamber will provide background currents around 10^{-9} to 10^{-8} amp.

*β-Ray Ionization detectors are also available, but not in common use. Differences result from the β-ray source (e.g., Kr^{85}, Ni^{63}) used to ionize the gas since an α particle produces around 10^3 times more ions than a β particle over the range of ionization chamber voltages. A β-ray detector would have to be operated as a proportional-type counter at a much higher voltage, around 550 volts, to produce equal ion currents. This high voltage is undesirable. Alternatively, a β-ray detector could achieve the same result by incorporating a larger amount of β emitter.

#Devices or techniques used in other fields that upon suitable modification or use in a hybrid mode offer some possibility for future mine detection devices.

Most organic compounds will be detected because their ionization potentials are in the range 9 to 11 ev; however, two important flame gases, CO and CO_2, which have ionization potentials of 14.1 and 14.4 ev respectively, will not be detected. The argon detector is best suited for very small concentrations of gases. It is relatively insensitive to changes in detector body temperature.

This device could possibly be used to detect combustible organic vapors. It would complement the ionization detector because of the latter's inability to detect organic vapors.[65] Used jointly, the ionization detector could be set at high sensitivity and its output signal would be an input to the Ar detector to sample the gas. If the argon detector responded according to some predetermined level, one would have a double check on the presence of a fire. The occurrence of false alarms could be minimized with this hybrid setup.

*Flame Ionization**

A hydrogen-oxygen (or air) flame, which makes up one of the electrodes, is used to induce electron emission in various types of organic and inorganic molecules having low work functions. Electrodes under imposed voltages are used to collect the resulting ions. High sensitivity, reasonable stability, moderate flow insensitivity, and linearity over a wide range are the highlights of this device.[96]

Use of this technique for a fire detection device is again limited to a hybrid system in a manner similar to the Ar Detector.

*Kryptonate-Type Sensors**

A laboratory study for detecting automobile pollutants, based on $PdCl_2$ kryptonate for CO, hydroquinone clathrate for NO_x, and PtO_2 kryptonate for hydrocarbons, is described by Goodmann and Donaghue.[97] The detection principle involves radiochemical exchange via kryptonates, which are solid sources containing the radioisotope $Kr.^{85}$ The solid kryptonates release activity upon subjection to gaseous constituents at a rate proportional to the concentration of the reacting gas. A Geiger-Müller tube is used to count the released radiation.

Selection of $PdCl_2$ for a CO sensor follows readily since $PdCl_2$ dispersed on silica gel is an indicator for CO. The lower limit of detection for the kryptonate $PdCl_2$ sensor was 125 ppm.

A sensitized hydroquinone-Kr^{85} clathrate, responding similarly to a kryptonate (i.e., rupture of the sensitized clathrate cage by oxidizing agents causes immediate release of Kr^{85}), was found to be highly sensitive to NO_2 (down to 2 ppm). However, since it gave no response to NO, the latter gas had to be oxidized to NO_2. The sensitized clathrate was subject to interferences at relative humidity above 90%.

The PtO_2 kryptonate sensor responded to various hydrocarbons (down to 13 ppm C_3H_8) and also to H_2.

Since this technique requires consumption of the sensing material for detection of the various species, it would be limited to discreet sensing in a hybrid setup

*Devices or techniques used in other fields that upon suitable modification or use in a hybrid mode offer some possibility for future mine detection devices.

for a fire detector based on CO and NO_x discrimination in a mine. However, the major drawback is with the NO determination, since essentially all NO_x is NO at flame temperatures, thus requiring an oxidation step to obtain NO_2. This is viewed as undesirable.

Laser Beam

Research at the Boreham Wood Fire Research Station in England has led to the development of a laser beam fire detection system for extended area coverage.[98] It operates on the principle of deflection of the laser beam due to differences in the index of refraction of the combustion gases versus air. Ambient fluctuations in temperature are discriminated against by tuning an amplifier to receive a frequency of 40-70 Hz. The corner-cube mirror used with a checkered mask prevents slight changes in the reflected beam due to small movements in the mirror mounting and the laser itself, respectively, from triggering false alarms. Although the laser device offers tremendous potential for large area coverage, its sensitivity to these movements and expected ease of damage from vibrations obviate its use in a mine.

Photoelectric

The basic requirements for photoelectric fire detectors are two: a light source (such as beacon lamp, light-emitting diode, or pulsed laser) and a detector (photocell, phototube, or solid-state device) to measure the radiant power of the light. Four different modes of operation presently used are based on the amount of light: (a) transmitted or absorbed by the medium*; (b) reflected; (c) scattered; and (d) refracted.

In the light transmission or absorption case, a light source and detector are arranged in line at opposite extremes of the test area, giving extended area coverage. When smoke crosses the beam path, the radiant power reaching the detector is reduced, which leads to a current reduction. This reduction can be monitored to sound an alarm at a predetermined value of light transmittance, absorbance, or specific optical density correponding to a given smoke concentration (2% smoke obscuration/ft is commonly used).

Extended area coverage is also provided with the reflection technique, although in a slightly different manner. Both the light source and the detector are integrated into a single unit. A mirror (possibly a suitable arrangement of mirrors) located at some predetermined position, not necessarily on the light source axis, is used to reflect light back to the receiver. Here the increase in radiant energy is used in appropriate circuitry to produce an alarm.

Photoelectric scattering devices contain the source and detector within a single unit, but unlike the beam devices they are open to the atmosphere. Smoke particles must be present in the sensing chamber in order to scatter the light beam so that it strikes the photocell. Extended area coverage is not provided with the scattering detector since the smoke contained in the sampling chamber represents a local

*Not commonly used as a fire detector.

property. Its response time is usually slower than the other two types of photoelectric detectors since it is a point-source detector. Auxiliary or backup heat detection is often provided with these detectors. This will minimize the effects of thermally induced smoke stratification mentioned earlier.

Refraction devices also contain the source and detector in a single unit. Locating a target disc in line with light source and detector causes light to be bent by refraction, when smoke particles enter the sensing chamber, around the disc onto the receiver.

The primary light sources in current use are beacon lamps (i.e., miniature incandescent lamps whose output spectrum resembles familiar blackbody radiation curves) and light-emitting diodes (LEDs). Detector stability is affected by lamp aging, film build-up on lens surface, or fluctuations in lamp supply voltage. Lamp life is a question of much concern; under normal use around 2 years is expected. Field experience indicates that shock and vibration can reduce life, particularly during power failure; also, lamp filaments are more fragile when old and cold. To overcome some of these difficulties, balanced ratio bridge arrangements are used. One photocell senses smoke scattered from a primary beam while the other views only the primary beam.[99]

The recent dramatic growth in the field of optoelectronics has led to the introduction of LED photoelectric detectors. Under excitation provided by an electrostatic field a junction diode can emit light or exhibit electroluminescence. GaAs is one of the best materials for infrared LEDs, while GaP and GaAsP are used to produce the visible spectrum. The main advantages for these devices functioning as fire detectors are their long life compared to lamps, low cost, and output power linearity with input current over a wide range. Their disadvantages include ease of damage by over-voltage and over-currents and the fact that radiant power output is temperature-dependent.

Because of the requirement for a rugged fire detector, LEDs are clearly preferred over beacon lamps. We likewise require the detector to be a solid-state device. Primary sensors include cadmium sulfide or cadmium-sulfoselenide photoconductors. Extended-area devices using mirrors also do not appear applicable to the mine environment for similar reasons as well as others cited earlier. Thus, we are left with the point-source detectors based on light scattering and refraction and light transmission or absorption.

In dusty mine environments the frequency of false alarms for the latter two detectors might limit further their applicability. However, scattering detectors are known to be rather insensitive to black smokes, e.g., 2% obscuration/ft for greyish white smoke corresponds roughly to 10% obscuration/ft for black smoke, and thus, at least for certain types of mines, reliable detection might be expected. Periodic removal of accumulated dust particles surrounding porous protective shrouds would be required. This can be accomplished by external means, whereas detector head disassembly is required for cleaning of electrode plates in ionization devices.

For wet mines containing water in aerosol form of fogs or mists, light transmission or absorption detectors, suitably calibrated for the light intensity in the mine, seem to afford potentially reliable fire detection capabilities. That is, both

the light source and receiver can be hermetically sealed and positioned in line (by means of a metal bar to prevent movement) for ceiling mounting.

*Filament Sensor**

Thermal Conductivity—A set of heated matched metal filaments (generally nickel, platinum, or tungsten at filament temperatures of around 200°C) or thermistors are used to follow changes in thermal conductivity. A pure carrier gas is passed over a reference junction while the carrier gas plus a mixture eluted from a suitable column passes through the detector element. In the differential-type setup, the resistance of the detector element changes relative to the fixed junction and is a measure of the concentration of the component in the gas stream.

It appears that with some modifications of this technique the device could function as a fire detector.[45] With air in a thin-walled, sealed reference compartment (of high-thermal-conductivity metal) and with the detector element open to the atmosphere, differences in composition and temperature will lead to bridge imbalance. One could also fabricate the two compartments out of different pore size electromesh screens. Variations in the mass throughput leading to thermal conductivity imbalances and/or in temperature in the two compartments will lead to bridge imbalance.

If the proposed device operates there are many unanswered questions pertaining to response time, the need of a separation column, etc. The latter does not appear to be necessary since we are not interested in resolving the various combustion products. Actually, some degree of separation will probably be obtained if fine electromesh screens are used. Study in this area appears warranted because this device could respond simultaneously to composition and temperature changes.

Catalytic Elements—Platinum wire, alloys, and activated platinum wound into a coil containing dual chambers (one chamber is inactive or sealed, the other open to atmosphere) in a Wheatstone bridge circuit is the usual sensing device.[64] Instruments are of two main types: remote head or sampling devices. Gases to be sampled reach the filaments through a sintered metal disc or protective gauze, which acts as a flame arrestor for prevention of flame propagation into a combustible mixture (as present in many gassy mines). Another set up has the complete bridge and possibly an amplifier located in the head such that its response is essentially independent of the location of the control unit.

Studies at the Safety in Mines Research Establishment (SMRE) of the United Kingdom have led to development of pellistors or elements for CH_4 sensing.[100,64] The ceramic catalyst consists of a mixture of thorium and palladium salts, which are decomposed by heating and then aged in a methane-air stream. The change in temperature of the element is followed by using the platinum coil as a resistance thermometer.

Selectivity toward a particular gas may be obtained by measuring the net signal from two catalytically active elements. Further selectivity may be obtained

*Device or techniques used in other fields that upon suitable modification or use in a hybrid mode offer some possibility for future mine detection devices.

through use of molecular sieves that allow only certain molecular diameters to reach the active element and by measuring signal differences between molecular sieves of different molecular pore sizes. Modifications of this basic technique also allow measurement of oxygen and certain inhibiting gases.

Besides the applications cited (combustible gas sensor, specific gases depending on molecular sieve diameters, etc.), these pellistor elements appear similar, at least on an overall basis, to the "Taguchi" type of POC sensor and thus might be expected to have fire detection applicability.

Solid-State Devices

"Taguchi" Gas Sensor—The Taguchi Gas Sensor (TGS), composed of bulk N-type metal oxides such as SnO_2, ZnO, and ferric sesquioxide, decreases its electrical resistance upon adsorption of deoxidizing or combustible gases such as CO, alcohol, volatile oil, carbon-dust-containing air, or smoke. Its ease of alarming in areas containing engine combustion products necessitates some judgment for its use in mines. However, its low cost is a definite plus and, assuming one can modify the sensor appropriately, it could receive widespread acceptance in the detection field. For mine applicability it may be limited to sampling applications in a hybrid setup.

Polymeric Film Sensors—The use of organic semiconductors with p-n junction devices for gas detection is detailed by Byrd[101]; recent studies using this approach are concerned with the development of a polymeric film fire detector.[102] The approach is based on the reversible and specific adsorption of gas on thin films of organic solids and the consequent change in density of electronic charge carriers. There are two different devices, based either on variation of charge carrier density as a source of current change under an applied voltage or on charge density—capacity change followed by variation of capacity.

Since direct capacitance or current measurements for low dielectric constant, low-conductivity films are difficult, amplification of the resulting charge is required. Two possibilities are as follows:

1. Combination of organic film and p-n junction of a silicon diode reverse biased; electrically, the high-resistance reverse current path of the diode is paralleled by the relatively conductive organic film.
2. Film used in conjunction with metal oxide silicon field effect transistor; here the separate capacitive variations in the film are amplified. Materials of interest include poly (phenylacetylene), poly (p-nitrophenylacetylene), poly (p-formamidophenylacetylene), poly (p-aminophenylacetylene), and various related or substituted compounds.

Bean[103] made an interesting study involving the use of stable lipid membranes with multiple resistance states as sensors for air-borne organic vapors based on membrane interface relations. Significant sensitivities to a number of organic compounds were obtained. Film resistivity studies have shown nonlinear characteristics for films cast upon glass or aqueous surfaces. Films prepared from ethyl

cellulose, polycarbonate, or polyamide (1-3 micrometers thick) or combinations thereof and with lipids may have significant nonlinear resistances including partial rectification characteristics.

Leibecki[104] examined impregnation of flurocarbon polymers with electrically conducting oxides of rhenium and molybdenum. It appears that the intent here is eventually to develop a polymeric film sensor having properties similar to or better than "Taguchi" devices.

Presently, these studies are in the research stage, and it appears that considerably more effort is required before a commercial prototype will become available. Although it may be premature to speculate on the fire detection capabilities of any devices based on polymeric film sensor techniques, it appears that sensitivity to various gases might preclude acceptance as a fire detector, similar to the present NFPA stand concerning "Taguchi" devices. In the mine environment false alarming seems to present a potentially serious problem. Low-cost gas-sensing capability is a possibility; however, selectivity or specific species sensitivity must be demonstrated.

Gas Sensors

This section is limited to a review of pertinent techniques for sensing the important fire gases CO, CO_2, and NO_x from a discrimination viewpoint and the O_2 deficiency. An excellent breakdown of the principal methods used in gas sensing, the range, and region of applicability is given by Chebotarev *et al.*[71] Many of the more compact sensors are outgrowths of innovations in the field of gas chromatography.

Detectors besides the specific classification of Chebotarev[71] are broadly classified as integral and differential types.[64] Integral types record the properties followed in a number of steps while differential detectors respond essentially instantaneously to gas properties. The latter have high sensitivity, precision, and other desirable properties, whereas the former integral types have low sensitivity, narrow range of applicability, high inertia, etc. Most detection systems are, therefore, of the differential type. The input-output signal response relationship for nearly all differential detectors is given by the simple linear differential equation

$$\tau \frac{dy}{dt} + y = kx \tag{2}$$

where x = input,

y = output, such as electrical or pneumatic signal,

τ = time constant of detector,

k = amplification factor related to detector sensitivity, and

t = time.

We will not utilize this type of classification here. Furthermore, complex devices requiring specialized maintenance such as mass-spectrometers and ultraviolet or infrared spectrophotometers are also excluded. Only the highlights of the more interesting sensors as pertains to the present fire detection applications are con-

sidered, since they are treated elsewhere. We are excluding, therefore, length of stain indicator tubes, cumbersome wet chemical techniques, and other noncontinuous operations that do not have readily replaceable sensing elements. Previously cited references[64, 70, 71, 72] as well as others[105, 106, 107] contain much useful descriptive information dealing with CO, CO_2, NO_x, and O_2 sensors. Carrol and Armstrong[106] examine the accuracy and precision of several portable gas detectors and make comparisons of portable detector response to CO and CO_2 with sensitive long-path infrared analyzers.

CO, CO_2, NO_x, and O_2 Sensing Techniques

CO Sensing Techniques—Martin and Hoenig[63] present a detailed review of CO monitoring techniques. The classification method is according to mode of operation, i.e., colorimetric change, catalytic, etc.

The sensor in the Unico Corporation CO alarm is high-impact polystyrene, which changes color from yellow to brownish-black in the presence of CO. The change of color is followed in a photoelectric system. Maintenance is a major problem, since the detection sensor must be replaced after exposure to CO. In a similar way, light reflection from a $PdCl_2$ disc, which darkens when CO is present, is used for CO detection.

The Mine Safety Appliances CO detector (MSA Model C portable CO sensor) consists of beds of active and inactive hopcalite catalyst surrounding two thermistors in a Wheatstone bridge circuit.[108] An exothermic reaction of CO to CO_2 leads to bridge imbalance and causes a proportional "upscale" meter reading, thereby giving the CO concentration. This device can be hooked up to an alarm system. Catalyst life limits its use to a toxic gas detector, since ambient CO levels in a mine are fairly high during certain periods. High humidity will shorten its life and tobacco smoke will seriously impair the accuracy of this instrument.

Electrochemical techniques for CO sensing are commercially available in the Energetics Science, Inc., CO Ecolyzer.[109] The sensor consists of a three-electrode system—a sensing electrode, a counter electrode, a reference electrode in a housing containing sulfuric acid solution, and two face plates. The reaction scheme is

$$CO + H_2O \rightarrow CO_2 + 2H^+ + 2e^-$$

between working and counter electrodes,

$$O_2 + 4H^+ \rightarrow 2H_2O - 4e^-$$

at counter electrode, giving the overall cell reaction

$$2CO + O_2 \rightarrow 2CO_2$$

Besides the known interference from ethylene (1 ppm ethylene corresponds to 3 ppm CO),[109] MSA has observed that 50 ppm NO gives 40 ppm CO on the Ecolyzer.[40] MSA found that 20% acidic solution of $K_2Cr_2O_7$ on silica gel completely removed the NO interference.

A polarographic sensor for detection of CO is described by Bergman and

Windle.[110] In the SMRE device a metallized membrane (anode) in conjunction with a membrane of polytetrafluoroethylene (PTFE) 6 μm thick or silicone rubber coated with a thin layer of gold and a similar layer of silver by vacuum evaporation (which serves as the cathode in the cell) and then with anodic catalyst metals is under laboratory study for use as a portable CO sensor. This device, operating similarly to the filament sensor described elsewhere, in a remote head/amplifier setup, offers considerable potential for monitoring CO buildup in worked-out or abandoned mine regions. Coupled with a similar sensor for O_2, the ratio of CO to O_2 deficiency could be monitored at a central station with instantaneous signalling since live current is involved in contrast to the long time delays obtained during pneumatic conveying of gases through tubes.

An earlier proposed fuel cell sensor for CO is described by Wagner.[45] Here fuel cell operation may be compared with an electrochemical cell in that conventional fuels react at the anode while O_2 or air reacts at the cathode. The electrodes, which are usually sintered porous metals, serve as reaction sites where electrons are transferred to an external circuit. The electrodes are considered inert since they do not undergo the mass transfer exchange accompanying oxidation and reduction as in a typical electrochemical cell. The fuels most often used are hydrogen, hydrocarbons, and hydrazine.

Carbon monoxide fuel cells are unimportant in the fuel cell field. They appear to be of potential use in the fire detection area. For example, mixed electrocatalysts (e.g., $Pt\text{-}WO_2$) consume appreciable amounts of CO along with H_2, and alloy electrocatalysts promote selective anodic oxidation of hydrogen. An application of this principle would seem to offer promise for combustion gases. With a 5 N H_2SO_4 liquid electrolyte and special CO-sensitive electrodes, appreciable voltage changes occur for small variations of CO.[111] From a best estimate of the graphical results, an increase in CO concentration from just 1% to 3% leads to a voltage increase from 13.75 mv up to 23.8 mv. Changes of this magnitude could easily be monitored and circuitry designed to trigger an alarm.

Sensitive optical methods for detection of CO (and also CO_2) applicable to single station sampling use non-dispersive infrared 4.65 μm (CO_2 band referred to is often the 4.4 μm band). The system consists of a source (e.g., nichrome wires, lasers) of radiation usually chopped mechanically, a cell through which the sample gas flows and radiation is absorbed by the CO molecule, a detector for the radiant signal, and appropriate filters, depending on desired discrimination. The detector is usually set to measure the amount of radiation transmitted, i.e., the energy that would reach the detector if there were no absorption in the gas, less the amount absorbed.[64] The sample and reference cells are metallic parallel tubes, gold plated to ensure maximum radiation at the sensor. Cell lengths vary from 0.1 to 25 cm, with length being a compromise between sufficient length for a strong signal and short enough to have a reasonably linear full-scale output. The solid-state detectors of interest have been reviewed previously. Interference to the CO band from CO_2 is generally negligible except for the case of low CO in a high CO_2 concentration. Here filters are required to cut off the lower absorption spectrum of CO_2.

An interesting trigas development study for CO, CH_4, and NO_2 using both infrared (for CO and CH_4) and visible (NO_2 channels) is currently under develop-

ment by Andros, Inc. for the Bureau of Mines.[112] The analyzer is a portable (hand-held) battery-powered device for in-mine monitoring applications. Present test results for noise, sensitivity, and stability on both infrared and visible channels showed peak-to-peak drifts of 7 ppm NO_2 and 2 ppm CO. Extended life tests are currently in progress.

CO_2 Sensing Techniques—The NDRI analyzers are similar in behavior to the CO analyzers with differences in the solid-state sensors, filters, etc.

An interesting solid-state semiconductor sensor for CO_2 (also H_2 and CH_4) from Thunder Scientific operates in the range 0-100% CO_2 in air with a 0 to 1% resolution at temperatures from 60° F to 90° F.[113] No requirements for chemical or catalytic conversion are necessary prior to sensing. Response times are not cited. Bennewitz[114] discusses the operating behavior of this solid-state sensor for a humidity sensor (gas sensor behavior is considered proprietary to Thunder Scientific). Since the humidity sensor behavior is described as a bulk effect semiconductor device that changes resistivity as water molecules drift through a precise array of crystals, similar behavior for CO_2 might be expected. Response times as a humidity sensor are given as 300 milliseconds or less for 63% of the reading.

A novel carbon dioxide sensor based on monitoring changes in electrical resistance of an anion-exchange resin proportional to the ambient partial pressure of CO_2 is described by Leitz.[115] Change in resistance is due to increased ionization of a weakly ionized base in the presence of a slightly acid gas. The optimum material consisted of a condensation polymer of resorcinol, formaldehyde, and triethylenetetramine. A dual chamber device containing two sensing elements (one being a reference) was used to minimize humidity and temperature effects. Interesting features of the sensor are its size—around 50 in^3, weight of less than 6 ounces, and a power requirement of less than 0.5 watt.

Another interesting electrochemical sensor is detailed by Reyes *et al.*[116] The sensor utilized a pH electrode and Ag-AgCl reference electrode with a tris (hydroxymethyl) aminomethane buffer containing an enzyme carbonic anhydrase as a catalyst. A FET incorporated into the probe assembly increased electrical stability as well as simplified the electronics. Response times of less than 2 seconds for a step change in partial pressure of CO_2 from 14 to 35 mm Hg were obtained.

A recent device based on pressure/density differences for CO_2 (also O_2 sensing) analysis is described as an analog fluidic gas concentration sensor.[117,118] The sensor is a passive resistor bridge that consists of two identical flow channels, each of which consists of a linear resistor and a nonlinear orifice resistor. A reference gas and a similar gas mixture (identical to the reference except for the presence of one other gas component) flow through the individual channels. When the sample gas is the same as the reference, the differential output pressure is zero; when different, the differential pressure is a measure of the concentration of the foreign gas. This technique is limited to clean regions, since orifice clogging is possible in dusty or contaminated atmospheres.

NO_x Sensing Techniques—Detailed reviews of NO_x instrumental techniques are given by Snyder *et al.*[107] The recently accepted approach for NO_x analysis involves chemiluminescence, which is the emission of light directly from a chemical

reaction. For NO_x the reactions are

$$NO + O_3 \rightarrow NO_2^* + O_2$$

$$NO_2^* \rightarrow NO_2 + h\nu.$$

Ozone is generated at low pressures from high-voltage discharge in O_2 or air. For NO_2 measurement the sample is passed through a converter in which NO_2 is converted to NO. If NO and NO_2 are both present, NO_x is measured. NO_2 may be obtained by difference from the NO_x and NO concentrations. A number of commercial instruments are described in Verdin's monograph.[64] An application of chemiluminescent techniques for measurement of NO_x from pyrolysis/combustion of nitrogen-containing plastics is described by Sarofin *et al.*[62]

O_2 Sensing Techniques—Paramagnetic O_2 analyzers, because of their inherent stability and lower maintenance requirements than electrochemical analyzers, are used for nearly all continuous analysis in the percentage range.[64] They are recommended, therefore, for the pneumatic sampling approach. At low concentrations or when portability or remote sampling is required, electrochemical techniques come to mind.

The polarographic sensor of SMRE[110] described previously was developed originally for sensing oxygen deficiency. It is essentially identical to the CO sensor, the principal difference being omission of the anodic catalyst metals. This device is not affected by shock, vibration, wind speed, and orientation. The device is temperature-sensitive, since O_2 permeability of the PTFE membrane was found to be exponentially dependent on temperature. Since resistance of commercial thermistors varies similarly with temperature, the two functions can be matched over several decades of temperature and thus compensated. Over the range 5 to 35°C SMRE has obtained an overall accuracy of $\pm 2\%$ of the reading. An application of a polarographic O_2 membrane sensor in CO sampling for evaluation of fire fighter exposures is given by Sidor *et al.*[119] General design considerations for membrane-covered polarographic gas detectors are covered by Lucero.[120]

An application of the fluidic oscillator technique for O_2 sensing[121] (also H_2 detection) is similar to the approach for CO_2 described previously.

Single-Station Detection Using Sampling Tube Networks

Continuous monitoring of CO, CO_2, NO_x, and O_2 deficiency using sensitive NDIR analyzers for CO and CO_2 and chemiluminescent and paramagnetic analyzers for NO_x and O_2, respectively, at a single station* from several spatial locations appears appropriate for detecting spontaneous combustion and other slow-burning phenomena. A gas sampling system would require probes, tubing, traps and filters, remotely actuated solenoid valves, and a high-capacity pump to produce a pressure gradiant (auxiliary pumping on the analyzers is also required).[122,123,94] Computer processing of the data is often desirable.[123]

*At ground level or at selected horizontal levels close to likely sources of spontaneous combustion; rooms at these levels are assumed to be dust-free; instruments are also shock and vibration protected through appropriate mountings.

Time lags in concentration sampling resulting from fluid dynamical factors in the tubing, filters, and traps, as well as instrumental delays in the various analyzer types, are not of primary concern since they are small (for reasonable tube lengths and a properly designed system) relative to the time scales for spontaneous combustion. However, in order to design an optimum system that might also apply to more rapidly occurring combustion modes, i.e., one that allows frequent sampling from the individual locations at a minimum cost, a knowledge of the important parameters controlling response time is important. An exact solution of a differential form of Poiseuille's equation for isothermal and adiabatic conditions in straight and curved tubes to predict response times has recently been given by Hertzberg and Litton.[124]

DETECTOR EXPERIMENTS

Detector experiments on which parts of this study are based are covered by Wagner.[45] Additional detector performance data appear to be limited.[94,95,125,126] The interested reader should consult the referenced works for details.

DETECTOR SPACING AND POSITIONING CRITERIA

As mentioned earlier, there is no national code for mines similar to the NFPA codes dealing with detector positioning and arrangement within residential and commercial embodiments. Whether such a code is feasible or desirable is subject to conjecture, since mines vary so widely in distribution of combustibles, ventilation patterns, and nature of supports (timbered supports as in the deep-vein miles of Northern Idaho contrasted to the absence of timber as in certain cavernous trackless mining operations). Nevertheless, some rules of thumb would be desirable. For example, for a smooth ceiling, housing fire detectors subjected to a radially expanding ceiling jet and other restrictions, notably drafts induced by room ventilation and non-temperature stratifications at the ceiling, Alpert[127] shows that

1. Fire detectors should be located a vertical distance below the ceiling of no more than 6% of the ceiling height; and
2. For optimum response time, fire detectors should be spaced at intervals of one-fourth of the ceiling height. Spacings smaller than this value will yield no significant improvement in detector response time. While calculations such as this might have some applicability in a mine, such as in intake or exhaust shafts, the complicated ventilation patterns as well as random ceiling obstructions and tunnel shapes obviate general applicability.

An alternative approach is to examine the positioning of detectors based on continuous release of a suitable aerosol and location of the selected detector at the point of maximum response. This should permit in-mine sensitivity positionings to be made.

SUMMARY REMARKS ON THE STATE-OF-THE-ART SURVEY

An examination of the state of the art of fire detection devices and gas sensing techniques as they pertain to applicability in metal and non-metal mines reveals numerous problem areas. A summary of the more important factors follows.

1. High frequency of false alarming for sensitive products-of-combustion (ionization and photoelectric types) and optical-view field detectors (infrared and ultraviolet types), in industrial and residential embodiments, poses serious problems concerning reliable use of these devices in metal and non-metal mines. Less sensitive direct contact or thermal detectors appear capable of operating reliably in various mine environmental extremes; however, their inability to detect slow smoldering fires precludes widespread applicability.
2. Insensitivity of conventional products-of-combustion fire detectors to normal mine operations involving emission of aerosol contaminants from diesel equipment and blasting is, at best, tenuous. It appears that development of a hybrid or integrated systems approach involving simultaneous sampling of gaseous species in the ratios CO/NO_x and CO_2/NO_x (to discriminate against diesel and blasting operations), with detection of one or more fire signatures (smoke, radiant energy, or heat sensing), is required for reliable fire detection in mines.
3. Neither ionization nor photoelectric (scattering or refraction types) detectors, which are open to the mine atmosphere, appear to offer long-term reliability in active mine areas. Maintenance problems are judged to be more critical for the ionization detector. Furthermore, a strong dependence on flow velocity precludes use of the ionization detector in regions close to ventilation fans and/or in ventilation ductworks. Operating a sealed photoelectric detection system based on light obscuration or transmittance appears to afford some promise for reliable detection.
4. Use of sampling tubes to monitor combustion products at a central station appears promising for detection of slowly developing phenomena, such as spontaneous combustion and slow smoldering fires.
5. Not much is known about optimum detector positioning and spacing in mines. Protection methodology based on accepted NFPA installation standards for industrial or residential environments is *not* applicable to the mine problem.

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FIRELITER—REVIEW OF 1975 FIRE RELATED JOURNAL LITERATURE
(Indexing Fire Articles from Titles)

B. W. KUVSHINOFF
L. J. HOLTSCHLAG
J. B. JERNIGAN
B. E. HESS

Applied Physics Laboratory
The Johns Hopkins University

The FIRELITER feature following this article is a collection of 1975 tables of contents of several journals that are prominent in fire science and technology. A subject index has been prepared from individual words and word strings in the titles. FIRELITER is the result of an effort to provide an overview of a representative sampling of the published fire literature. We encourage readers to comment on the result.

We feel strongly that by simply bringing together the tables of contents of various fire journals annually, we are providing fire researchers and practitioners with a convenient, desk-top literature search tool. Moreover, because of the diversity of the journals covered, we expect to see a freer transfer of ideas from one area of fire specialization to another.

This is the second issue of FIRELITER, covering the 1975 fire journal literature. Five journals that did not appear in the first FIRELITER have been added: *Archives of Thermodynamics and Combustion, BRE News, Journal of Hazardous Materials, Minnesota Fire Chief,* and *VFDB Zeitschrift*. The *Journal of Hazardous Materials* is a new title.

To familiarize readers with the general scope and content of the various journals, brief descriptions are presented indicating the frequency of publication, publisher, language, subject scope, and special features.

The introduction to the first FIRELITER details some of the strengths and weaknesses of indexing from titles. Those who have not read that introduction should do so to gain an insight into the use of the FIRELITER index.[1] Among other things, we confess to recasting and enriching a few titles to obtain index-worthy entries and to standardize spellings to improve the grouping of identical concepts. This was done cautiously and sparingly in the first FIRELITER. Having

[1]A discussion of fire information based on the Soviet *Fire Protection Abstracts Journal* can be found in *FRAR*, Vol. 14, No. 3, 1972.

heard neither shrieks of delight nor screams of anger, we have elected to extend these practices a bit more in this second effort. To illustrate the nature of some of these changes, we have converted terms such as fireman to firefighter, 22-story to highrise, and have spelled out names for chemical formulas. Consequently, readers should be aware that the titles printed here do not always coincide exactly with the phrasings of the original article titles.

Several of the journals contain editorial comments, brief news items, announcements of meetings, and the like. These by and large have been omitted. Mostly we tried to include substantive articles, which we generally define as signed, at least a page in length, and containing information that appears to have lasting value.

We trust these interventions contribute more help than harm to users of the FIRELITER indexes. Further, we hope that authors will not be unduly discomfited by the few changes we have made to their original titles.

As before, we solicit comments on FIRELITER from readers to assist and guide us in improving future annual compilations of journal article titles.

The references in the indexes consist of mnemonic abbreviations of the journal titles, volume number, issue number in parenthesis, and page number. For example, ComFla23 (1) 1 refers to *Combustion and Flame,* Volume 23, No. 1, page 1.

Perhaps it is not premature to say a few words about a new announcement service, the *Fire Technology Abstracts Journal,* which is scheduled to appear in July 1976, and bimonthly thereafter.

This new abstracts journal, sponsored by the National Fire Prevention and Control Administration, will cover the current English-language and foreign fire technology literature somewhat in the fashion that *FRAR* covers the scientific and research fire literature. In addition, however, the new journal will have subject and author indexes in each issue and will contain a larger number of abstracts.

JOURNAL DESCRIPTIONS

Archives of Thermodynamics and Combustion (Archiwum Termodynamiki i Spalania); quarterly; Polish Academy of Sciences, Warsaw; articles in English, French, German, Polish and Russian, summaries in English, Polish, and Russian; publication of articles on thermodynamics, heat and mass transfer, physics and chemistry of combustion, detonation and explosion processes; features survey of news and publications, advance announcements of articles to be published in next issue; annual index in final issue.

BRE News; quarterly; British Building Research Establishment; English; articles devoted to the building industry and fire research; features - research news, recent publications, people and events.

Combustion and Flame; bimonthly; journal of the Combustion Institute; American Elsevier Publishing Co., NY: English; publication of experimental and theoretical investigations of combustion phenomena and allied matters; features - meeting announcements and reports, book reviews; annual author and subject indexes in December issue.

Combustion Science and Technology; bimonthly; Gordon and Breach Science Publishers; English; publication of new results, discoveries and developments in flame and fire research, flame radiation, chemical fuels and propellants, reacting flows, thermochemistry, atmospheric chemistry and combustion phenomena related to aircraft gas turbines, chemical rockets, ramjets, automotive engines, furnaces, and environmental studies.

Fire Chief Magazine; monthly; H. Marvin Ginn Corp., Chicago, Ill.; English; articles of operational fire department interest on all aspects of fire occurrence, statistics, organization and administration, fire prevention and control; features - editorial, news, meetings, new equipment, related industrial news, free literature, people and events, advertiser index, reader inquiry cards.

Fire Command; monthly; publication of the National Fire Protection Association; articles on all aspects of firemanship; features - letters, legal insight, news and new products, people, editorial, buyer's guide; annual index in December issue.

Fire Engineering; monthly; English; devoted to firemanship, training, state of the art, etc.; features - volunteers corner, letters, fire schools, book shelf, round table, fire equipment digest, people, advertisers index, reader service card; annual index in December issue.

Fire Engineers Journal; quarterly; the official journal of the Institution of Fire Engineers; English; articles and brief contributions of fire-department level interest; features - letters, apointments, promotions and retirements.

Fire International; quarterly; journal of the world's fire protection services; UNISAF House, Kent, England, trilingual (English, French, and German), summaries in Spanish; each issue devoted generally to one theme (administration, organization, conferences, protection, etc.); feature-advertisers index.

Fire Journal; bimonthly; membership publication of the National Fire Protection Association; English; articles on fire incidence, safety, statics, training, association meetings, events, and affairs; features bimonthly fire record, public involvement, letters, NFPA library accessions, advertisers index, subject index.

Fire Prevention Science and Technology; quarterly; membership publication of the Fire Protection Association, England; English; information on new developments in fire protection for engineers and scientists; brief article summaries in English, French, and German.

Fire Protection Review; monthly; England, Benn Brothers Ltd.; topical articles on fire incidents, equipment, meetings, events, people; feature-advertisers index; annual subject index in December issue.

Fire Technology; quarterly; published by the National Fire Protection Association, USA; English; articles on fire protection research and engineering; features - editorials, news and meetings, reviews and notes, technical notes, readers' forum, abstracts, index.

Journal of Fire and Flammability; quarterly; Technomic Publishing Corp., Westport, Connecticut, USA: English; information on fire exposures and characteristics and fire and flammability behavior of individual and composite materials and systems in various environments, test methods and apparatus, theories and techniques of fire prevention, retardation and extinguishment, chemistry of fire retardants, and toxicology of combustion products; subject index in October issue.

JFF/Combustion Toxicology Supplement; quarterly; Technomic Publishing Corp., Westport, Connecticut, USA: English; all aspects of combustion toxicology; subject index in October issue.

JFF/Consumer Product Flammability Supplement; quarterly; Technomic Publishing Corp., Westport, Connecticut, USA: English; fire and flammability behavior of individual and composite materials and systems in various environments; subject index in October issue.

JFF/Fire Retardant Chemistry Supplement; quarterly; Technomic Publishing Corp., Westport, Connecticut, USA: English; retardation and extinguishment of fires, chemistry of fire retardants; subject index in October issue.

Journal of Hazardous Materials;

Lab Data; quarterly; published by Underwriters Laboratories, Inc., USA; English; articles devoted to product safety topics, test discoveries, equipment and product ideas; features - news briefs, notes from the testing bench.

Minnesota Fire Chief; bimonthly; sponsored by the Minnesota State Fire Chiefs Association, USA; English; brief communications on fire occurrence topics, information, news, state fire news, etc.

National Safety News; monthly; a National Safety Council Publication, USA; Enlgish; articles on all aspects of domestic, commercial, and industrial safety; annual June issue devoted exclusively to fire protection and security; features - literature review under "Safety Library," reprints section, advertisers index; annual subject index in December issue.

Physics of Combustion and Explosion (Fizika Goreniya i Vzryva); bimonthly; Siberian Branch of the Academy of Sciences of the USSR, Novosibirsk, USSR; Russian; Table of Contents in English; Translated in entirety into English as "Combustion, Explosion and Shock Waves"; articles on research in combustion theory, combustion of solids, liquids and gases, explosions, flames, ignition, self-heating and self-ignition, heat transfer; features occasional section on current conferences; annual author index in final issue.

VFDB Zeitschrift; quarterly; publication of the Association for the Advancement of German Fire Protection, Inc., West Germany; German; summaries in English and French; publication of articles on fire protection research and technology, annual reports and communications of the Association; features - literature review, memoranda; annual index published as separate in first issue of succeeding year.

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EXPANSIONS OF REFERENCE ABBREVIATIONS

ArchTC	Archives of Thermodynamics and Combustion
BRENWS	BRE News
ComFla	Combustion and Flame
ComSciT	Combustion Science and Technology
FEngJ	Fire Engineers Journal
FirChf	Fire Chief Magazine
FirCom	Fire Command
FirEng	Fire Engineering
FirInt	Fire International
FirJrn	Fire Journal
FirTec	Fire Technology
FPRev	Fire Protection Review
FPSTech	Fire Prevention Science and Technology
JFFCPF	JFF/Consumer Product Flammability Supplement
JFFCT	JFF/Combustion Toxicology Supplement
JFFFRC	JFF/Fire Retardant Chemistry Supplement
JFFLAO	Journal of Fire and Flammability
JHazMat	Journal of Hazardous Materials
LabDat	Lab Data
MinnFC	Minnesota Fire Chief
NSNews	National Safety News
PhysCE	Physics of Combustion and Explosion
VFDBZ	VFDB Zeitschrift

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DCPA01-76-C-0289

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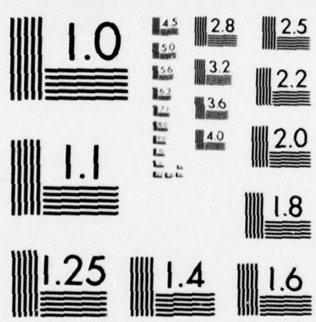

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ABSTRACTS AND REVIEWS

A. Prevention of Fires, Safety Measures, and Retardants

Arscott, J. A., Street, P. J., and Twamley, C. S. "The Application of Water Sprays to Control Fires in Coal Milling Plant at Power Stations," *Fire Prevention Science and Technology,* (7) 4-11 (November 1973)

Subjects: Fires; Burning processes; Water sprays; Coal milling; Power stations

Safety in Mines Abstracts 23 No. 46
Safety in Mines Research Establishment

Discusses the physico-chemical and mechanical problems involved when water is applied to coal fires — water repellent nature of coal, reactions between hot coal and water vapor producing flammable gases, droplet size control, control of momentum.

Baker, W. E., Kulesz, J. J., Ricker, R. E., Bessey, R. L., Westine, P. S., Parr, V. B., and Oldham, G. A. (Southwest Research Institute, San Antonio, Texas) "Workbook for Predicting Pressure Wave and Fragment Effects of Exploding Propellant Tanks and Gas Storage Vessels," Contractor Report NASA CF - 134906 for the National Aeronautics and Space Administration (November 1975) See Section I.

Balek, M. "Preventive Measures Against Frictional Sparking During Rock Cutting," *VVUU Rep.,* (122) 50 pp. (1974) (in Czech.)

Subjects: Ignition prevention; Prevention of ignition

Safety in Mines Abstracts 23 No. 479
Safety in Mines Research Establishment

The author reports on tests of cutting tools, in particular of those used in power loaders, in contact with rock and evaluates the risk of ignition by frictional sparks. The report includes a draft classification of rocks, based on tests of their igniting capacity, and suggests preventive measures.

Baratov, A. N. *et al.* "Combustibility of Some Organometallic Compounds," *Khimicheskaya Promyshlennost',* (8) 29-31 (1972)

Subjects: Flammability; Organometallic compounds

Safety in Mines Abstracts 23 No. 271
Safety in Mines Research Establishment

Reports on results of investigations into the fire hazard associated with some organometallic compounds. Because of the readiness with which these compounds react with oxygen and water, techniques involving the use of ampoules were developed for studying their fire risk properties.

Beery, G. T., Clodfelter, R. G., Gandee, G. W., Morris, J. L., and McCoy, J. R. (Air Force Aero Propulsion Laboratory) **Spear, D. M., Wight, D. C., Klein, J. K. and Reed, T. O.** (Aeronautical Systems Divsion) "Assessment of JP-8 as a Replacement Fuel for the Air Force Standard Jet Fuel JP-4 Part 1. Assessment of JP-8/JP-4 Fuel in Noncombat Environment," *Air Force Aero Propulsion Laboratory Final Technical Report No. AFAPL - TR - 74-71, Part 1, (June 1972 - April 1975)* Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio (1975)

Subjects: Fuel; Jet fuel; Jet fuel evaluation; JP-8; JP-4

Authors' Abstract

This report is an assessment of JP-8 as a replacement fuel for the Air Force standard jet fuel JP-4. All facets of the problem are examined including fire safety under combat and noncombat conditions, crash fire safety, storage, handling and maintenance safety, laboratory testing, gunfire testing, flight testing, cost and availability, and impact on current Air Force weapons systems. The report concludes that a significant improvement in overall fire safety could be achieved by conversion to JP-8. However, additional investigation into problems related to low temperature ground start and altitude relight should be accomplished prior to conversion.

Brackebusch, A. P. (Intermountain Forest and Range Experimental Station, Ogden, Utah) "Gain and Loss of Moisture in Large Forest Fuels," *U.S.D.A. Forest Service Research Paper INT-173* (1975)

Subjects: Fuel moisture content; Fire weather; Fire danger rating

Author's Abstract

Equations for predicting moisture in large fuels were developed from data gathered at Priest River Experimental Forest and Boise Basin Experimental Forest. The most important variables were beginning moisture content of the fuel, duration of precipitation, amount of precipitation, and the sum of the mean temperature of an observation period. Sensitivity and precision of the equations are weak. Predictions could be used as a guide. Moisture content of logs varied according to type of exposure.

Brown, J. K. (Intermountain Forest and Range Experimental Station, Ogden, Utah) **and Roussopoulos, P. J.** (North Central Forest and Range Experimental Station, Saint Paul, Minnesota) "Eliminating Biases in the Planar Intersect Method for Estimating Volumes of Small Fuels," *Forest Science 20* (4) 350-356 (1974)

Subjects: Planar intersect method; Fuel volumes; Line intersect; Forest fuels; Sampling methods

Authors' Abstract

In testing accuracy of the planar intersect method, bias due to nonhorizontal orientation of woody particles ranged from 8 to 39%. Bias due to the use of arithmetic average diameters instead of quadratic mean diameters for solving volume equations ranged from 9 to 16 %. Theory is presented showing how the average secant of nonhorizontal particle angles and quadratic mean diameters of particles eliminate biases. To help users correct biases, quadratic mean diameters and average secants of nonhorizontal particle angles were determined for 0- to 0.6-cm, 0.6- to 2.5-cm, 2.5- to 7.6-cm diameter classes in slash for eight western conifers, two eastern conifers, and oak, and in naturally fallen material for the western conifers.

Chicarello, P. J. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Integration of Fire Protection into Automated Storage Systems at Naval Shore Facilities," Volume I. *Factory Mutual Research Corporation* AD-A009 520/8WI, 53 pp. (1974)

Subjects: Integration of fire protection; Automated storage systems; Naval shore facilities

The history and development of rack storage fire protection is reviewed and the present state of the art is surveyed. The constraints imposed on fire protection by the construction and operational requirements of high rack storage systems are stated, and two methods of integrating fire protection into rack storage systems are described. Economic considerations are briefly discussed.

Cybulski, W. "Studies of Triggered Barriers," *Fifteenth International Conference of Safety in Mines Research,* Karlovy Vary, Czechoslovakia, 13 pp. (September 1973)

Subjects: Mine fires; Triggered barriers

Safety in Mines Abstracts 23 No. 403
Safety in Mines Research Establishment

Describes research carried out to determine the effectiveness of the barriers as a function of their distance from the ignition source, the type of explosion (violent or mild), the length of the time intervals between the initiation of the explosion and

the arrival of the flame at the barrier and the amount of methane when the barrier is placed at a short distance from the ignition source.

Donat, C. "Explosion Pressure Venting and Explosion Proof Design of Containers and Apparatuses," *Ztschr. VFDB 22* (4) 138-142 (November 1973) (in German)

Subjects: Explosion; Excessive pressures; Venting; Explosion proof container design

Safety in Mines Abstracts 23 No. 45
Safety in Mines Research Establishment

The author describes several testing installations and gives results. He explains the effect of various protection measures, mentioning the effect on surroundings of pressure waves and explosion flames. A supplement to the directive VDI 2263 is in course of preparation; this will deal with the important points to be observed in pressure venting in the case of flammable dusts.

Frost, J. S. and Haines, D. A. (North Central Forest Experimental Station, Saint Paul, Minnesota) "Fire Weather Stations in North Central and Northeastern United States," *U.S.D.A. Forest Service Research Note NC-194* (1975) See Section J.

Furman, R. W. (Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado) "Estimating Moisture Content of Heavy Forest Fuels," *Forest Science 22* (2) 135-139 (June 1975)

Subjects: Fire hazard; Weather effects; Fuel moisture content

Author's Abstract

The specification of moisture contents in forest fuels is an integral part of any workable fire-danger rating system. This paper presents a linear model for estimating the moisture content of the 100-hour timelag fuels. The variables in the model include yesterday's computed value for 100-hour timelag fuel moisture. Today's observed 10-hour timelag fuel moisture and a binary variable which is set if rain has occurred in the 24 hours prior to the observation time. The standard error of estimate for a data set of 69 points including 25 days during which some precipitation occurred was 0.65%.

George, C. W. (Intermountain Forest and Range Experimental Station, Ogden, Utah) "Fire Retardant Ground Distribution Patterns from the CL-215 Air Tanker," *U.S.D.A. Forest Service Research Paper INT-165* (1975)

Subjects: Aerial fire suppression; Fire retardant chemicals; Models; Predictions of ground distribution patterns; Drop heights; Air tankers

Author's Abstract

Several fire retardants in current use were dropped from the Canadair CL-215 aircraft to determine drop height effects and for evaluation of the tank and gating system. Mathematical models for each retardant and load size were developed for predicting the effects of drop height on ground distribution as shown by the retardant recovery, area of coverage, and contour (fireline) length as functions of concentration level.

Grumer, J. (U.S. Bureau of Mines, Pittsburgh, Pennsylvania) "Recent Developments in Coal Mine Fire and Explosion Prevention Research," *U.S. Bureau of Mines Information Circular 8616* (1973)

Subjects: Research in mine fires; Mine fires; U.S. Bureau of Mines; Triggered barriers

Abstracted by G. Fristrom

Fiscal year 1973 fire and explosion studies seek to develop methods for detecting and quenching ignitions of gas in the face area by means of passive or triggered barriers, and to detect incipient fires early enough for easy extinguishment. Research involves air velocities for lifting coal and rock dusts. Surveys on the adequacy of rock dusting, chemical agents to quench gas or coal dust explosions, and nozzle sprays of extinguishants were made.

Helfman, R. S., Deeming, J. E., Staub, R. J., and Furman, R. W. (Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado) "User's Guide to AFFIRMS: Time Share Computerized Processing for Fire Danger Rating," *U.S.D.A. Forest Service General Technical Report RM-15* (1975)

Subjects: Fire danger rating; Computers; Fire weather

Authors' Abstract

Procedures for processing fire danger data utilizing a time-share computer via a remote terminal are presented in non-technical language for persons without computer background. Input includes fuels and weather information; output includes narrative messages sent from other users, displays of observed and forecasted weather, and fire danger indexes. Observed fuels and weather input data are automatically checked for errors and archived. Examples are given.

Johnson, L. D., Canfield, J. A., Lull, D. B., and Morris, T. F. "The Development of a System to Suppress and Extinguish Fully Developed Coal Dust Explosions: Progress Report," *Naval Weapons Laboratory, Technical Report NWL-TR-3030,* Dahlgren, Virginia 140 pp. (September 1973) See Section N.

Kiltgaard, P. S. and Williamson, R. B. (University of California, Berkeley,

California) "Impact of Contents on Building Fires," *Journal of Fire and Flammability*, Consumer Products Flammability *2* 84-113 (1975)

Subjects: Building fires; Fire load, contents; Fires in buildings; Polymeric materials

Abstracted by G. Fristrom

The impact of new man-made polymeric materials used in construction of furniture and other household items on building fires is discussed. Several burn experiments involving common household plastic items are described. Growth of fire in a compartment from ignition to flashover is discussed with particular reference to spread mechanisms involving plastics. Development of standard flammability tests for plastic materials in their functional environments is recommended, as is labeling building content items with materials of construction and appropriate warnings.

Kissel, F. N., Nagel, A. E., and Zabetakis, M. G. "Coal Mine Explosions: Seasonal Trends," *Science 179* 891-892 (March 1973) See Section L.

Knudson, R. M. and Williamson, R. B. (University of California, Forest Products Laboratory, Richmond, California) "Influence of Temperature and Time upon Pyrolysis of Untreated and Fire Retardant Treated Wood," *Wood Science and Technology 5* 176-189 (1971)

Subjects: Pyrolysis; Fire retarded wood

Authors' Summary

Untreated and fire-retardant treated specimens of Douglas-fir were pyrolyzed up to 30 minutes at temperatures of 250°, 350° and 550° C. Various cell wall components viewed under the scanning electron microscope appeared to decompose at rates related to their chemical composition. No structural differences were noted between pyrolyzed specimens of untreated wood and wood treated with a mixture of zinc chloride and sodium dichromate. Cell walls of specimens treated with a mixture of urea, monammonium phosphate, and glucose exhibited thermoplastic behavior as a result of exposure to high temperatures.

Kotelevskii, P. A., Ivanov, G. D., and Makarenko, P. I. "Prevention and Localization of Coal Dust Explosion," *Bezopas. Truda Prom. 18* (5) 23-24 (1974) (in Russian)

Subjects: Mine explosion; Prevention of coal dust explosion; Coal dust explosion localization

Safety in Mines Abstracts 23 No. 618
Safety in Mines Research Establishment

General Discussion of methods used in Soviet coal industry to prevent and contain coal dust explosions which include cement limestone dusting, water washing, binding settled dust, dust settling by water curtains, measures for combating coal dust explosions in near face areas, main water barriers, etc.

Leonard, J. T. and Clark, R. C. (Naval Research Laboratory, Washington, D.C.) "Electrostatic Hazards Produced by Carbon Dioxide in Inerting and Fire Extinguishing Systems," Final Report, *Naval Research Laboratory No. 7920* for The Department of The Navy, Naval Ships Engineering Center (August 1975) See Section I.

Lie, T. T. (Division of Building Research, National Research Council of Canada, Ottawa, Canada) "Characteristic Temperature Curves for Various Fire Severities," *Fire Technology 10* (4) 315 (1974) See Section G.

Lie, T. T. (National Research Council Canada, Ottawa, Canada) "Probabilistics Aspects of Fire in Buildings," *National Research Council of Canada,* Division of Building Research Technical Paper No. 422 (June 1974) See Section L.

"Lightweight Breathing Apparatus," *Mining Magazine 130* (1) 47 (January 1974) See Section N.

Lipska, A. E. and Amaro, A. J. (Stanford Research Institute, Menlo Park, California) "Development and Evaluation of Practical Self Help Fire Retardants," Final Report, August 1973 - April 1975, under Contract DAHC20-70-C-0219 for the Defense Civil Preparedness Agency (April 1975)

Subjects: Fire retardants, self help; Magnesium ammonium phosphate; Ammonium bromide solution; Thermal hardening procedures; Wood roofs; Nylon and dacron polyester carpets; Toxic products

Authors' Abstract

A study was conducted (1) to improve surface penetration of the retardant formulations for existing wood roofs and to evaluate the retardance efficiency of the resulting thermal hardening procedures, and (2) to investigate practical ways of incorporating retardants into nylon and dacron polyester (polyethylene terephthalate) carpets. Magnesium ammonium phosphate sprayed on and interstitially precipitated in existing wood roofs provides at least a Class C fire protection rating that should withstand weathering for at least five years. This self-help treatment is effective if the component chemical solutions are applied to roofs that are at least five years old. The depth of retardant penetration increases with the age of the roof, since exposure of the roof to the elements increases the porosity of the wood. The depth of retardant penetration in roofs much less than five years old is very shallow, resulting in only seasonal protection against firebrands.

The guidelines, derived from the Parker-Lipska arithmetical expression for choosing effective retardants can be applied to cellulosics in general—be it paper, cotton, or wood. In addition, similar guidelines can be applied to those synthetics that are char formers and whose general mode of decomposition parallels that of cellulose. However, different guidelines remain to be developed for the noncharforming synthetics.

A 20% NH_4Br solution was applied to both the nylon and dacron polyester carpets and was found to prevent flame spread and to reduce the generation of toxic products. Although the chemical is water soluble, it is relatively inexpensive and can be easily applied with a rug shampooer once a year by the average citizen.

Although it is possible to permanently retard both the nylon and the dacron carpets, the procedure entails chemical incorporation of a retardant into the polymer chain itself, which, although potentially feasible during manufacture, would be impractical as a self-help remedy for the average citizen.

Marden, R. M., Lothner, D. C., and Kallio, E. (North Central Forest Experimental Station, Saint Paul, Minnesota) "Wood and Bark Percentages and Moisture Contents of Minnesota Pulpwood Species," *U.S.D.A. Forest Service Research Paper NC-114* (1975)

Subjects: Weight scaling; Jack pine; Black spruce; Balsam fir; Quaking aspen; Balsam poplar

Authors' Abstract

To help increase the use of bark for fuel or products, information is presented on the relative proportions of bark and wood by volume and weight, and also moisture contents (ovendry basis) for five northern Minnesota pulpwood species.

Myers, G. C. and Holmes, C. A. (Forest Products Laboratory, Madison, Wisconsin) "Fire Retardant Treatments for Dry Formed Hardboard," *Forest Products Journal 25* (1) 20-28 (1975)

Subjects: Fire retardants; Hardboard; Building codes

Authors' Abstract

Building codes are becoming more stringent on the use of wood fiber products in structures because of the flammability of these products. Twenty-one fire-retardant chemical systems known to provide some fire retardancy to solid wood were investigated for their effectiveness in improving fire performance of dry-formed hardboard. Three types of retardants—water-soluble salts, liquid ammonium polyphosphates, and curing-type organic phosphates—were applied at 10 or 20% of the fiber weight; this was followed by a phenolic resin treatment. Fire performance in an 8-foot and in a 2-foot tunnel furnace was determined as were strength properties. Results indicated that a moderate reduction in flame spread (to 60%) can be obtained at the 10% level of treatment with some reduction

in modulus of rupture. Increasing the level to 20% gave further reductions in flame spread with little additional reduction in bending strength, particularly with a treatment of disodium octaborate tetrahydrate-boric acid, a water-soluble salt.

Nettleton, M. A. (Central Electricity Research Laboratories, Leatherhead, England) "Pressure as a Function of Time and Distance in a Vented Vessel," *Combustion and Flame 24* 65-77 (1975)

Subjects: Explosion pressures; Venting; Diaphragm bursting

Author's Abstract

Rates of fall in pressure have been measured at different positions in a number of differently-shaped vessels vented by means of bursting diaphragms. It is demonstrated that the qualitative features of the experimental pressure histories are predicted by characteristic theory. Attention is drawn to the importance of the reflection of the expansion wave which may partly explain the existence of twin pressure peaks typical of vented explosions and which can result in the reversal of pressure gradients within the vessel.

Pineau, J., Giltaire, M., and Dangréaux, J. "Efficacy of Explosion Vents. Study of Dust Explosions in 1, 10 and 100 m^3 Vessels," *Cah. Notes Docum. Instn. Natn. Sécur. Prév. Accid. Travail, Note No. 881-74-74* 75-86 (in French)

Subjects: Explosion prevention; Dust explosions

Safety in Mines Abstracts 23 No. 268
Safety in Mines Research Establishment

Describes experiments carried out at Cerchar in order to examine the validity of the law $X = \frac{k}{\sqrt[3]{V}}$ (X = venting coefficient, i. e., ratio of volume V of vessel to the discharge gap surface necessary, in order not to exceed a given explosion pressure). The authors give a brief description of the experimental conditions and present results concerning the variation of the maximum explosion pressure in the 1, 10 and 100 m^3 vessels as a function of the dust concentration and of the venting coefficient X. They conclude by explaining some mechanisms intervening in the development of the explosion.

Powell, J. H. (Safety in Mines Research Establishment, Sheffield, England) "Assessment of the Maintenance of the Effectiveness of Safety Schemes by Inspection and Age Replacement of Protective Devices," *Journal Institute Maths Applics 16* 81-92 (1975) See Section L.

Sheldon, F. L. and Moran, J. W. (Air Force Aero Propulsion Laboratory, Wright Patterson Air Force Base, Ohio) "Void Filler Ballistic Fire Protection for Aircraft Fuel System Dry Bays," Final Report, October 1972 - September 1973,

Air Force Aero Propulsion Laboratory Report No. AFAPL-TR-74-126 (July 1975)

Subjects: Void filler materials; Fire suppression; Aircraft fuel tank protection; Gunfire testing; Fragment impacts; Survivability/vulnerability

Authors' Abstract

This program was conducted to determine the feasibility of using a void filler material in dry bays that are adjacent to aircraft fuel tanks to provide a fire protection capability against incendiary gunfire and fragment type threats. All test configuration results showed that with filler material in the dry bay, dry bay void fires were eliminated. The probability of fires external to the dry bay approached 0% if reticulated polyether polyurethane flexible foam was installed with a 5% to 10% compression factor. These tests were conducted without airflow over the exterior dry-bay skin.

Shimada, H. "Fire Resistivity of Irradiated Nuclear Fuel Shipping Cask," *Fire Research Institute of Japan Report 39* 30-34 (1975)

Subjects: Fire resistivity; Nuclear fuel shipping cask

Author's Introduction

It was found in the previous study that the full-scale casks (80 tons in weight, 1600 mm in dia and 5200 mm in length) would withstand the exposure to 800°C — 30 in fire, provided that a gap was formed between the shell and the inside lead-shield due to contraction of the latter on molding.

In the process of cask fabrication, the shells are generally subjected to a treatment of lining their surfaces with lead before putting a mass of molten lead into them, in order to get a better contact between the shell and the lead shield after the solidifying of the lead, so that the heat generated from the contained fuel may be more effectively dissipated outward.

This paper will describe the fire resistivity of the lead lining-treated casks and its comparison with that of untreated ones on the basis model experiments and theoretical analysis.

Smart, R. C. "Fire and Explosion Hazards from Static Electricity," *Occupational Safety and Health 3* (2) 66-76 (1973) (in German)

Subjects: Fire; Explosion hazards; Static electricity

Safety in Mines Abstracts 23 No. 473
Safety in Mines Research Establishment

After reviewing the nature of static electricity the author lists hazards from static electricity in certain industrial equipment and operations. A table gives the dust explosion characteristics of various powders. Several examples of how the hazards can be controlled are given.

Terpstra, J. "Dust Properties," *Proceedings of the Conference on Technical Measures of Dust Prevention and Suppression in Mines*, Luxembourg 11-13 October 1972, 241-271, European Communities Commission (1973)

Subjects: Suppression of dust; Mine safety

Safety in Mines Abstracts 23 No. 120
Safety in Mines Research Establishment

In the first part of this report a method is described for determining the volatility of the face dust from the ash content and the carbon content of this dust. Then the particle size distribution of face dust is determined from the cumulative particle size distribution. It appears that for particles between 0.7 and 8 μ diameter the logarithm of the particle size distribution function is linearly dependent on the logarithm of the particle diameter. The dependence of the coefficients in this linear relation on the ash content and the volatility of the face dust and the air velocity along the face is described.

Thorne, P. F. (Fire Research Station, Borehamwood, England) "The Strength of Fire Extinguishers," *Fire Prevention Science and Technology 12* 17-23 (1975) See Section E.

Wiersma, S. J. and Martin, S. B. (Stanford Research Institute, Menlo Park, California) "The Nuclear Fire Threat to Urban Areas," Final Report, August 1973 - April 1975, under Contract No DAHC20-70-C-0219 for The Defense Civil Preparedness Agency (April 1975)

Subjects: Nuclear fire threat; Structural fire dynamics; Structural fire behavior; Structural blast behavior; Blast fire response; Land use areas; Overpressure ranges

Authors' Abstract

The *nuclear fire threat* to urban areas was evaluated in a five-year *structural fire dynamics* program. The program (1) experimentally determined the dynamic characteristics of full-scale building fires, and (2) used the findings of the structural fire behavior experiments along with existing knowledge of *structural blast behavior* to predict the *combined blast-fire response* of an urban area to a nuclear attack.

In the experimental program, wood-frame buildings were burned to determine the dynamic behavior of one type of structure. Parameters which were varied included wind velocity, fuel contents in the rooms, degree of simulated blast damage to the building, number of buildings burning at one time, initial fire size, and ceiling material in the rooms. Measurements included burning rates, fire spread rates, toxic gas concentrations, air temperatures, and induced inflow winds.

To predict the combined blast-fire response of an urban area to a nuclear attack, two *land-use areas*, residential and built-up commercial, and two *ranges of overpressure*, 2 to 5 psi and 5 to 15 psi, were considered. The predictions are summarized

in a table. A striking result of the study is the uniform coverage of debris, leaving very few debris-free areas except in built-up commercial land-use area at the 2-5 psi overpressure range.

Wilson, S. G. "Fire Protection in the Food Industry," *Food Processing Industry 42* (506) 29, 31 (1973)

Subjects: Explosions; Pyrophoric materials; Fires in ducts; Electrical fires; Minor fires; Extinguishers

Abstracted by G. Fristrom

Explosions, pyrophoric materials, fires in ducts, electrical fires, fire risk during maintenance, extinguishers, fixed installations, work fire organization, and deposition of apparatus are discussed in relation to fire protection in the food industry.

B. Ignition of Fires

Abduragimov, I. M., Driker, G. Ya., Ryvkin, A. M., Shvartsman, N. A., and Yantovskiy, S. A. "Inhibition of High and Low Temperature Hydrocarbon Fuel Combustion Reactions," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Afanas'ev, G. T., Bobolev, V. K., and Dolgov, V. I. "Contribution to the Theory of Mechanical Initiation of Solid Explosives," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Akinin, G. I. *et al.*, "Ignition of Rich Acetylene Air Mixtures," *Khimicheskaya Promyshlennost' 8* 32-33 (1972)

Subjects: Ignition; Acetylene air mixtures; Fire risk; Temperature of ignition

Safety in Mines Abstracts 23 No. 269
Safety in Mines Research Establishment

In order to establish the reason for the low temperature ignition of acetylene air mixtures and to observe the explosion characteristics, the authors determined the ignition temperature of mixtures with a large excess of combustible at atmospheric pressure.

Azatyan, V. V. and Aleksandrov, E. N. "Study of the Multiple Ignition of Carbon Monoxide under Static Conditions," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Balek, M. "Preventive Measures Against Frictional Sparking During Rock Cutting," *VVUU Rep. 122* 55 pp. (1974) (in Czech) See Section A.

Ballal, D. R. and Lefebvre, A. H. (Cranfield Institute of Technology, Cranfield, England) "The Influence of Spark Discharge Characteristics on Minimum Ignition Energy in Flowing Gases," *Combustion and Flame 24* 99-108 (1975)

Subjects: Spark ignition; Minimum ignition energy

Authors' Abstract

The electrical aspects of spark ignition in flowing combustible mixtures have been investigated in a specially designed, closed circuit wind tunnel in which a fan was used to drive the gas through a 9 cm square working section at various levels of pressure and at velocities up to 100 m/sec. The turbulence intensity in the ignition zone was varied between 1% and 15%. Turbulence scales ranged from 0.2 cm to 0.8 cm. The methods employed in the generation and measurement of turbulence have been fully described elsewhere [5]. The ignition unit supplied capacitance sparks of "rectangular" form whose energy and duration could be varied independently. The optimum spark duration for minimum ignition energy was found to be independent of turbulence intensity, but to vary appreciably with pressure, velocity and mixture strength. Measurement of the energy released during a spark discharge showed that it was linearly proportional to gap width and increased slightly with increase in pressure and velocity. The energy required to effect spark ignition was reduced by the use of electrode materials having low conductivity and low boiling point, and also by locating the spark electrodes with their axes parallel to the direction of the flow.

Bloshenko, V. N., Merzhanov, A. G., Peregudov, N. I., and Khaykin, B. I. "Theory of Gas-Phase Ignition of a Drop," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Bobolev, V. K., Karpukhin, I. A., and Teselkin, V. A. "The Role of Chemical Interaction of Components upon Shock Excitation of an Explosion in Mixtures of Ammonium Perchlorate and Fuel," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Custer, R. L. P. and Bright, R. G. (National Bureau of Standards, Washington, D.C.) "Fire Detection: The State of the Art," *Final Report NASA CR-134642* National Aeronautics and Space Administration under Contract No. NASA Order C - 506273 (June 1974)

Subjects: Fire detection; Code requirements, fire detection; Testing, fire detectors; Standards, fire detectors; Fire signatures

Authors' Abstract

The current state-of-the-art in fire detection technology is reviewed considering the nature of fire signatures, detection modes used, test methods, performance requirements, and code requirements for fire detection. Present trends in standards development and recommendations for future work are included. An extensive bibliography is provided.

Desy, D., Risbech, J. S., and Neumeier, L. A. "Research Finds Methane Can Ignite by Frictional Sparks Between Aluminum and Rusty Steel," *Coal Age 12* 65-68 (November 1973)

Subjects: Explosion protection; Spark ignition; Methane; Frictional sparks; Aluminum; Rusty steel

Safety in Mines Abstracts 23 No. 44
Safety in Mines Research Establishment

The authors describe research carried out by the U.S. Bureau of Mines to establish the incendivity of frictional sparks between aluminum alloys and rusty steel, to investigate differences between aluminum alloys and to evaluate substitute materials for the aluminum steel combination. Reference is made to British and German experiments on the subject.

Eckhoff, R. K. (Chr. Michelsen Institute, Bergen, Norway) "Towards Absolute Minimum Ignition Energies for Dust Clouds?" *Combustion and Flame 24* 53-64 (1975)

Subjects: Minimum ignition energy; Dust ignition

Author's Abstract

A review of the literature related to spark ignition of dust clouds revealed that contrary to what is the case of gases, the spark energy required for igniting a given dust cloud is markedly dependent, even by orders of magnitude, upon the characteristics of the spark discharge, in particular the discharge time. By using a specially designed spark generator producing sparks of optimal discharge characteristics, it was found that airborne clouds of various dusts could be ignited by considerably smaller spark energies than hitherto published minimum ignition energies for similar dust clouds. Thus, with these optimal sparks the minimum ignition energy for lycopodium was found to be about 6 mJ, for wheat grain dust containing a considerable fraction of coarse material, about 12 mJ, for sulphur less than 0.3 mJ, and for a fine quality flake aluminum somewhere between 0.3 and 0.9 mJ. By keeping in mind that this type of optimal sparks is associated with capacitive discharge circuits in which more than 90% of $\frac{1}{2}CV^2$ is lost in the external circuit resistance, and therefore only less than 10% delivered in the spark, an approximate estimate of the electrostatic hazard may be obtained by multiplying by a factor of ten the "absolute" minimum ignition energies found.

Elyutin, V. P., Mitin, B. S., and Samoteykin, V. V. "Influence of High-Temperature Oxidation on the Particular Features of Ignition of a Finely Dispersed Aluminum Powder," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Ezhovskiy, G. K., Mochalova, A. S., and Ozerov, E. S. "Ignition and Combustion of a Magnesium Particle," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Fedotov, N. G., Sarkisov, O. M., and Vedeneev, V. I. "Determining the Probabilities of Heterogeneous and Homogeneous Deactivation of Deuterium Molecules," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gavrilin, A. I., Mel'nikov, M. A., and Shneyder, V. B. "Ignition of Initiating Explosives by an Electrical Spark," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gel'fand, B. E., Gubin, S. A., Kogarko, S. M., and Mironov, V. N. "Dynamics of Ignition of a Gas Liquid Fuel Mixture Behind the Front of a Weak Shock Wave," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gray, B. F. (University of Leeds, Leeds, England) "Critical Behavior in Chemically Reacting Systems III. An Analytical Criterion for Insensitivity," *Combustion and Flame 24* 43-52 (1975) See Section G.

Grigor'ev, Yu. M. "Evaporation and Ignition of a Drop of n-Pentane in an Oxidizer Medium," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Grosse-Wortmann, H. "Ignition Limits of Hydrocarbon Oxygen Nitrogen Systems at Elevated Pressures and Temperature," *Chemie - Ingr. - Tech. 46* (3) 111 (1974) (in German)

Subjects: Spontaneous reactions; Explosions; Ignition limits; Hydrocarbon - oxygen-nitrogen

Safety in Mines Abstracts 23 No. 250
Safety in Mines Research Establishment

Describes a test method for the determination of the ignition limits of ethylene, propylene, butadiene 1,3, ethyl benzol mixed with air and with air enriched with nitrogen at various pressures and temperatures.

Kalabukhov, G. V., Ryzhik, A. B., Yusmanov, Yu. A., Sidorov, V. M., Osipov, B. R., and Faerman, S. N. "Influence of the Reaction Kinetics Properties of an Igniting Flow on the Burning of Aluminum Powders," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Klochkov, I. S. "Excitation of an Explosion When a Metal Surface Rubs Against an Explosive," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Klyauzov, A. K., Arsh, M. M., Madyakin, F. P., and Filaretova, G. A. "Ignition of Metal Powders in the Combustion Products of a Model Fuel," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Korchunov, Yu. N. and Pomerantsev, V. V. "Mechanism of the Process of Ignition of Natural Solid Fuels", Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Krivulin, V. N., Lovachev, L. A., Baratov, A. N., and Makeev, V. I. "Investigation of the Influence of Acceleration on the Ignition Concentration Limits", Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kudryavtsev, E. M., Gluzberg, E. I., and Krikunov, G. N. "Experiment in Prevention of Spontaneous Ignition of Coal in Worked Out Area," *Ugol' 47* (12) 50-51 (December 1973) (in Russian)

Subjects: Ignition; Coal; Mine fires; Prevention of spontaneous ignition

Safety in Mines Abstracts 23 No. 196
Safety in Mines Research Establishment

Describes experiments in combating spontaneous ignition of coal in worked out areas of the Kostenko mine by means of an increase in the rate of advance of the face and by spraying the area prior to caving with a mixture of liquid glass and 1.2% ammonium chloride.

Kuznetsov, V. R. "Influence of Fluctuations of Temperature and Concentration on Ignition Delay in a Turbulent Flow," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Law, C. K. (General Motors Research Laboratories, Warren, Michigan) "Asymp-

totic Theory for Ignition and Extinction in Droplet Burning," *Combustion and Flame 24* 89-98 (1975)

Subjects: Ignition; Extinction; Droplet burning

Author's Abstract

The quasi-steady diffusion flame structure in droplet burning is analyzed, in the limit of large activation energy, for a one-step Arrhenius reaction in the gas phase. The characteristic ignition-extinction S-shaped curve is produced with segments of it corresponding to a nearly frozen flow regime, a partial burning regime, a premixed flame regime, and a nearly equilibrium regime. Critical Damköhler numbers for ignition and extinction, as well as correction factors to the mass evaporation rate to finite activation energy, are obtained. Close mathematical and physical analogies exist between the present problem and the counterflow problem recently analyzed by Liñán such that through appropriate transformations most of his numerical results can be readily utilized.

Lisitsyn, V. I., Pirozhenko, A. A., and Vilyunov, V. N. "Induction Period in the Ignition of a Disperse System," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Letyagin, V. A., Solov'ev, V. S., Boyko, M. M., and Kuznetsov, O. A. "Investigation of the Initiation of Liquid Explosives by Means of a Capacitive Sensor," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Merzhanov, A. G., Gal'chenko, Yu. A., Grigor'ev, Yu. M., and Mashkinov, L. B. "Ignition of an Aluminum Wire," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Muratov, S. M., Makharinskiy, V. M., Afanas'ev, G. T., and Postov, S. I. "Ignition of Pyroxylin at High Pressures and Temperatures," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Powell, F. and Billinge, K. (Safety in Mines Research Establishment, Sheffield, England) "The Frictional Ignition Hazard Associated with Colliery Rocks," *The Mining Engineer* p. 527 (July 1975)

Subjects: Frictional ignition; Ignition by friction; Colliery rocks

Authors' Synopsis

Most of the firedamp ignitions in British coal mines occur as a result of coal-cutting machines meeting rock. Petrological examination and rubbing tests on

colliery rocks have shown that rocks (other than pyrite) that give ignitions generally contain more than 30 percent by volume of quartz particles greater than 10 microns, and that the quartz particles are usually larger than 70 microns. An indication of the incendivity of quartzitic rocks can be obtained in the field by the application of a few simple physical tests.

Rock-cutting experiments on a practical scale show that a reduction in pick speed can reduce the probability of ignition and that, at any given pick speed, worn picks increase the probability of ignition over that for new picks. The correct application of water can greatly reduce the probability of ignition.

Raftery, M. M. "Ignition Properties of Dust Air Mixtures," *Chemical Process 20* (2) 55-59 (1974)

Subjects: Ignition; Dust fires

Safety in Mines Abstracts 23 No. 477
Safety in Mines Research Establishment

A study was made of flame propagation from selected industrial dusts and dust mixtures, which gave controlled variation of explosibility in small scale tests, a large-scale vertical tube which is approximately the size of small industrial plant, and a full industrial-scale cyclone plant. Dusts tested include methyl cellulose, polyvinylidene chloride, phenol-formaldehyde resin, urea-formaldehyde resin, ABS, epoxy resin, polyethylene, polypropylene and rubber.

Salamandra, G. D., Ventsel, N. M., and Fedoseeva, I. K. "Measurement of Gas Velocity During the Ignition of Fast Burning Gas Mixtures in Pipes," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Schumann, W. "Fires Caused by Electrostatic Charges," *Sicherheit 19* (1) 4-6, (2) 28-30, (3) 56-60 (1973) (in German)

Subjects: Ignition by static electricity; Fires; Electrostatic charges

Safety in Mines Abstracts 23 No. 16
Safety in Mines Research Establishment

An historical and a theoretical part dealing with static electricity in general and the basic units used is followed by a description of the standard methods of measurement of electrostatic charges and of the prevention or removal of such charges. In the final part, the author demonstrates, using simple examples, how even nonspecialists can detect electrostatic charges, assess the resulting hazard and take the initial steps to deal with it.

"Spontaneous Combustion; Control by Bentonite Injection," *Colliery Guard 222* (4) 117, 107 (April 1974)

Subjects: Mine fires; Spontaneous ignition; Bentonite injection

Safety in Mines Abstracts 23 No. 624
Safety in Mines Research Establishment

Describes the way this has been carried out in the Doncaster Area of the NCB by injecting Bentonite into strata, gateside packs, wastes and voids. Detection is by capsule samples and by a UNOR system monitoring CO at a number of critical points. A similar article on page 107 of the same issue, "Bentonite seals", describes experiences in the use of the substance for the same purposes at Parkside Colliery in the NCB North Western Area. Both articles give details of methods of mixing and pumping the Bentonite.

Stockstad, D. S. (Intermountain Forest and Range Experimental Station, Ogden, Utah) "Spontaneous and Piloted Ignition of Pine Needles," *U.S.D.A. Forest Service Research Note INT-194* (1975)

Subjects: Forest fuel ignition; Ignition; Pilot ignition; Spontaneous ignition; Pine needle ignition

Author's Abstract

Spontaneous and piloted ignition of ponderosa pine (Pinus ponderosa Laws.) needles were investigated in an isothermal atmosphere. Four levels of sample moisture content were tested and minimum heat flux intensities required to produce ignition, times to ignition, and surface temperatures at time of ignition were recorded. Piloted ignition occurred at lower flux intensities and in less time than did spontaneous ignition. A significant difference in delay time to ignition was found to exist for sample moisture contents above 7.7%.

Strokin, V. N. "The Process of Ignition and Combustion of Hydrogen in a Supersonic Flow," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Vodyankin, Yu. I., Dubnov, L. V., and Maurina, N. D. "On the Mechanisms of Initiation of Explosives by Friction," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Voinov, A. N., Nechayev, S. G., and Turovskiy, F. V. "Some Features of Ignition of Gas Mixtures by Incandescent Bodies in the Case of an Engine," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Zarko, V. E., Mikheev, V. F., Orlov, S. V., Khlevnoy, S. S., and Chertishchev, V.V. "Features of Hot Gas Ignition of Powder," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Zimont, V. L., Ivanov, V. K., and Oganesyan, S. Kh. "Self-ignition and Collapse of Combustion in the Stagnation Zone During the Flow of a Supersonic Stream of a Combustible Mixture Past a Plane Step and a Depression" Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

C. Detection of Fires

Abramov, F. A., Erakhmilevich, V. I., and Streimann, V. E. "The 'Sigma' CO Apparatus, A New Means of Detecting Underground Fires in Their Initial Stages," *Ugol' Ukr. 17* (8) 42-43 (1973) (in Russian)

Subjects: CO; Detectors; Mine fires; Underground fires

Safety in Mines Abstracts 23 No. 192
Safety in Mines Research Establishment

Gives the main technical specification of an apparatus for the continuous automatic monitoring of micro concentrations of CO in mine air and also the results of laboratory and mine trials of an experimental prototype.

Bergman, I. (Safety in Mines Research Establishment, Sheffield, England) "Electrochemical Carbon Monoxide Sensors Based on the Metallised Membrane Electrode," *Annals Occupational Hygiene 18* 53-62 Pergamon Press (1975)

Subjects: Electrochemical sensors; Carbon monoxide sensors; Metallised electrode

Author's Abstract

The 'metallised membrane electrode' is made by evaporating or sputtering metal on to a non-porous but gas-permeable polymer membrane. The 'amperostat' system consists of an electrochemical cell with two such electrodes and an auxiliary electrode in a control circuit. The system minimizes the effect of temperature on the background current. It also allows the electrocatalytic activation of carbon monoxide sensors to be controlled, and the activity to be maintained. Such sensors, made at SMRE or by collaborators, have given useful results in the field and in the laboratory over a number of years. Preliminary results suggest that, with ancillary equipment, they can make a significant contribution to the measurement of carbon monoxide at concentrations of 10 ppm upwards, and in a wide variety of gases: internal combustion exhaust gases, flue gases, cigarette smoke, exhaled air, polluted air, and air from environments that are subject to spontaneous combustion.

Firth, J. G., Jones, A., and Jones, T. A. (Safety in Mines Research Establishment,

Sheffield, England) "Solid State Detectors for Carbon Monoxide," *Annals Occupational Hygiene 18* 63-68 Pergamon Press (1975)

Subjects: Detectors; Solid state detectors; Carbon monoxide detectors

Authors' Abstract

The mechanism by which a gas can produce an electrical conductivity change in a semiconductor is outlined. The resulting advantages and disadvantages in the use of metal oxide semiconductors in gas detection devices for carbon monoxide are described and ways of reducing the disadvantages are discussed.

Nash, P. and Young, R. A. (Joint Fire Research Organization, Borehamwood, England) "The Performance of the Sprinkler in Detecting Fire," *Building Research Establishment Current Paper No. 81* (1975)

Subjects: Fire detection; Sprinklers

Authors' Abstract

It is shown that the response of sprinklers to a fire situation does not only depend upon the sprinkler itself, but also upon many characteristics of the building and the fire-load concerned. A proper study of all the factors can greatly help in deciding the design parameters of a system in order to make it as effective as possible in a specific application.

Packham, D. R., Gibson, L., and Linton, M. (Commonwealth Scientific and Industrial Research Organization, Commonwealth of Australia) "The Detection of Smoke in Air Conditioned and Ventilated Buildings," *Control 1* (2) 77-85 (1974)

Subjects: Smoke; Detectors, early warning; Air conditioned buildings; Ventilated buildings

Authors' Abstract

This paper introduces a new concept of 'early warning fire detection' for protecting air-conditioned or mechanically ventilated buildings by the use of ultra sensitive smoke detectors in return-air ducts. Some experiments have been done with a detector that can measure down to 0.01% m^{-1} smoke obscuration in such ducts. A first-approximation theory is proposed that should permit fire protection engineers to design appropriate installations, once smoke production rates of those materials most likely to be involved in a fire have been established, and the appropriate ignition time to 'alarm' assessed. A new approach to alarm levels is also presented, whereby a series of three alarms is used to deal with 'suspected' fires, 'incipient' fires, or 'active' fires. Some information is given about the normal smoke levels of three buildings (all telephone exchanges), smoke production rates of various materials, and the size of some incipient fires. A detector device being developed by the C.S.I.R.O. and A.P.O. is briefly described.

Senturia, S. D. (Massachusetts Institute of Technology, Cambridge, Massachusetts) "Fabrication and Evaluation of Polymeric Early Warning Fire Alarm Devices," Contractor Report NASA - CR - 134764 for the National Aeronautics and Space Administration, 106 pp. (1975)

Subjects: Polymeric fire alarm; Fire alarm devices

Author's Abstract

The electrical resistivities were investigated of some polymers known to be enhanced by the presence of certain gases. This was done to make a device capable of providing early warning to fire through its response with the gases produced in the early phases of combustion. Eight polymers were investigated: poly(phenyl acetylene), poly(p-aminophenyl acetylene), poly(p-nitrophenyl acetylene), poly(p-formamidophenyl acetylene), poly(ethynyl ferrocene), poly(ethynyl carborane), poly(ethynyl pyridine), and the polymer made from 1,2,3,6 tetramethyl pyridazine. A total of 40 usable thin-film sandwich devices and a total of 70 usable interdigitated-electrode lock-and-key devices were fabricated. The sandwich devices were used for measurements of contact linearity, polymer conductivity, and polymer dielectric constant. The lock-and-key devices were used to determine the response of the polymers to a spectrum of gases that included ammonia, carbon monoxide, carbon dioxide, sulfur dioxide, ethylene, acrolein, water vapor, and normal laboratory air. Strongest responses were to water vapor, ammonia, and acrolein, and depending on the polymer, weaker responses to carbon dioxide, sulfur dioxide, and carbon monoxide were observed. A quantitative theory of device operation, capable of accounting for observed device leakage current and sensitivity, was developed. A prototype detection/alarm system was designed and built for use in demonstrating sensor performance.

Trumble, T. M. (Air Force Aero Propulsion Laboratory, Wright Patterson Air Force Base, Ohio) "A Smoke Detection System for Manned Spacecraft Applications," Final Report, July 1970 - July 1974, *Air Force Aero Propulsion Laboratory Fuels and Lubrication Division Report No. AFAPL-TR-74-97* (June 1975)

Subjects: Smoke detection; Smoke particle distribution; Digital processors; Optical systems

Author's Abstract

This report describes the development, from concept to hardware, of an open path optical system for detecting smoke in manned spacecraft. Studies were conducted on the nature of light scattering through smoke as well as the nature of the particle statistics in smoke. These studies resulted in the selection of the 2537Å wavelength for smoke detection and the use of the 2537Å/3129Å ratio for discrimination from background particulates. Test results on the first laboratory unit constructed are included, and indicate that the concept is feasible and practicable. Present programs in this area are discussed in the Summary and Conclusions section of this report.

D. Propagation of Fires

Ezhovskiy, G. K., Mochalova, A. S., and Ozerov, E. S. "Ignition and Combustion of a Magnesium Particle," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Filippov, A. V. "Mechanism of Flame Propagation in a Forest Fire," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gurevich, M. A., Ozerova, G. E., and Stepanov, A. M. "Calculation of the Flame Propagation Rate in a Gas Suspension of Particles of a Solid Combustible," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Nigmatulin, R. I. and Vaynshteyn, P. B. "Flame Propagation in a Gas Mixture with Particles," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Rumanov, E. N. and Khaykin, B. I. "Regimes of Flame Propagation through a Suspension of Particles in a Gas," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Sukhinin, A. I. and Konev, E. V. "Combustion of Vegetable Matter for Various Compositions of the Ambient Medium," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Todes, O. M., Gol'tsiker, A. D., Gorbul'skiy, Ya. G., and Ionushas, K. K. "Propagation of a Plane Flame Front in Aerodisperse Systems" Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Wiersma, S. J. (Naval Surface Weapons Center, White Oak, Maryland, and Stanford Research Institute, Menlo Park, California) "Characteristics of Fires in Structural Debris," Final Report July 1973 - January 1975 for the Defense Civil Preparedness Agency under Contract No. DAHC 20-70-C-0300 (January 1975)

Subjects: Debris fire behavior; Fire spread; Gas effluents; Fuel size distribution; Fuel loading; Wind speed

Author's Abstract

Results of an experimental study of fire behavior in structural debris are reported. The study was conducted in two phases—the first in the laboratory, the second, involving large-scale burns, in the field. In both phases, debris-fire behavior was observed, rates of fire spread, durations of active flaming (i.e., residence time), and concentrations of gas effluents were measured, and the dependence of the observed and measured debris-fire characteristics on wind speed and on variables in debris composition were investigated.

In the first phase, 21 tests were conducted on 2½ x 9 ft debris beds in an enclosed laboratory where wind conditions were subject to control. The nonfuel-to-fuel ratio, fuel-size distribution, fuel-loading and wind speed were the experimentally controlled variables.

In the second phase, 10 tests using 8 x 13 ft to 8 x 30 ft debris plots were conducted out of doors in the natural wind. Experimental variables were the same as in Phase I except that fuel size was not varied. This is not believed to be a serious shortcoming of the large-scale tests because its effect in the small-scale tests was found to be unimportant.

Flame spread rates in debris are found to be strongly dependent on ambient wind velocity and the nonfuel-fuel ratio, only moderately dependent on fuel loading, and almost independent of fuel-size distribution. Debris composition and compactness also appear to have a tremendous effect on the flame spread rate, but these variables were not studied independently or extensively.

The ratio of concentrations of CO_2 and CO was nearly constant at about 20 for all test conditions and for both smoldering and flaming combustion. Thus, it appears that carbon monoxide yields will average about 100 pounds per ton of combustible debris, independently of the circumstances of burning.

E. Suppression of Fires

Abduragimov, I. M., Driker, G. Ya., Ryvkin, A. M., Shvartsman, N. A., and Yantovskiy, S. A. "Inhibition of High and Low Temperature Hydrocarbon Fuel Combustion Reactions," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Babkin, V. S. and V'yun, A. V. "Upper Limit of Flame Propagation with Respect to Pressure in a Bounded Volume," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Baratov, A. N. "Ignition: Flame Propagation, Concentration Limits, Status of the Problem," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Hoshino, M. and Hayashi, K. "Evaluation of Extinguishing Abilities of Fire Fighting Foam Agents for Oil Tank Fires," Report of *The Fire Research Institute of Japan 39* 59 (1975)

Subjects: Fluoroprotein foams; Light water; AER-O-Water AFFF; Testing extinguishants; Foam agents; Oil tank fires

Authors' Abstract

Presented in this report is information about the abilities of a protein-based foam, Light Water FC-200, and a fluoroprotein foam known as AER-O-Water AFFF for extinguishing gasoline fire in deep fuel layers with long preburn times in a steel tank. The tests were carried out indoors using a small scale steel tank, 1.5m square and 1.45m in height, with double sidewalls equipped with thermocouples. This double sidewall construction was to simulate the severe burning conditions of actual tank fires, i.e., the red heated wall and the hot fuel layer, etc.

The conclusion obtained from results of the tests may be summarized as follows.

(1) Where three foam agents used in the tests are applied gently to the burning surface using a fixed foam applicator, regular protein-based foam is only one agent that meets stringent sealability and burn back requirements for the protection of long preburning large scale gasoline tank fires having danger of reignition by heated sidewall and hot oil surface.

Light Water FC-200 and Fluroprotein foam AER-O-Water AFFF can seal up rapidly compared with protein-based foam, but they have poor resistance to burn-back and also are less efficient for long preburning gasoline tank fires.

(2) It may be considered that the fire extinguishing abilities of fluoroprotein foam (AER-O-Water AFFF) under the premixed condition were greatly reduced compared with both protein-based foam and Light Water FC-200.

(3) It was found that as preburning time increased, the extinguishing abilities of foam agents were greatly effected by changes in the depth of hot zone (70 - 80° C) and the temperature of the free board, especially near the burning surface.

(4) It was found that the analysis of the free board temperatures obtained by thermocouples on the inner sidewall opposite to the fixed foam applicator gave the extinguishing behaviors and extinguishing time of foam agents, without visual observations.

(5) Under the severe burning condition in large scale gasoline tank fires in deep fuel with long preburn times, the foam produced in fixed foam applicator was greatly affected by flame, highly heated sidewall and hot fuel layers. It is recommended that the application rate of protein-based foam should be required somewhat higher than the present recommended rate (0.1 gpm/ft^2) based on NFPA No. 11.

Karpinskiy, B. V., Ryabikin, Yu. A., Mansurov, Z. A., Dubinin, V. V., Gershenzon, Yu. M., and Ksandopulo, G. I. "Mechanism of the Effect of Synergism in the Combustion of Hydrogen with Additions of Diethylamine and Tetrafluorodibromoethane," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Krivulin, V. N., Lovachev, L. A., Baratov, A. N., and Makeev, V. I. "Investigation

of the Influence of Acceleration on the Ignition Concentration Limits" Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Law, C. K. (General Motors Research Laboratories, Warren, Michigan) "Asymptotic Theory for Ignition and Extinction in Droplet Burning," *Combustion and Flame 24* 89-98 (1975) See Section B.

Panin, V. F., Parfenov, L. K., and Zakharov, Yu. A. "Phenomenon of Three Flame Propagation Limits on the System H_2-O_2-N_2," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Sulimov, A. A., Obmenin, A. V., Korotkov, A. I., and Shushlyapin, P. I. "Low Velocity Regime of Explosive Transformation in Charges of High Density Solid Explosives," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Thorne, P. F. (Fire Research Station, Borehamwood, England) "The Strength of Fire Extinguishers," *Fire Prevention Science and Technology 12* 17-23 (1975)

Subject: Fire extinguishers

Author's Abstract

An international standards coordinating committee, the Comité Européen de Normalisation has set up Committee (CENTRI 2) to draft a European standard for portable fire extinguishers. One of the features under discussion is the strength of extinguisher bodies necessary to support their working pressures safely under all likely conditions, and to avoid damage by other means such as impact, storage loads, etc. This paper examines the available evidence on the basis of which suitable strength criteria can be decided.

Voskoboynikova, N. F. "Critical Detonation Diameters of Solutions of Solid Explosives," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Zimont, V. L., Ivanov, V. K., and Oganesyan, S. Kh. "Self-ignition and Collapse of Combustion in the Stagnation Zone During the Flow of a Supersonic Stream of a Combustible Mixture Past a Plane Step and a Depression," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

G. Combustion Engineering and Tests

Abrukov, S. A., Isayev, N. A., and Maksimov, Yu. Ya. "Study of the Influence of Electric Fields on Flame Stabilization and Oscillation," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Aldabayev, L. I. and Bakhman, N. H. "Influence of Additions of Solid Oxidizers on the Diffusion Burning of Polymers in Air," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Alekseev, Yu. I., Korolev, V. L., and Knyazhitskiy, V. P. "Measurement of Temperatures During the Linear Pyrolysis of Polymethylmethacrylate," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Alemasov, V. E., Dregalin, A. F., and Cherenkov, A. S. "Calculation of the Composition and Electrical Conductivity of the Heterogeneous Combustion Products of Chemical Fuels," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Alpert, R. L., Modak, A. T., and Newman, J. S. (Factory Mutual Research, Norwood, Massachusetts) "The Third Full Scale Bedroom Fire Test of the Home Fire Project. Volume I. Test Description and Experimental Data," Technical Report 21022.6. RC-B-48 under Grant No. NSF-GI 34734 X, Harvard University for The Home Fire Project, National Science Foundation, RANN Program (October 1975)

Subjects: Bedroom fire; Home fire project

Authors' Summary

Series of full-scale Bedroom Fire Tests (1973, 4, 5) has served as a focus of the joint Harvard-Factory Mutual Home Fire Project which seeks to minimize loss of life and property through the development of a better scientific understanding of fire ignition, growth and extinguishment. The program was sponsored by the National Science Foundation and recently by the National Fire Prevention and Control Administration.

The objectives of these Bedroom Fire Tests are: (1) to provide detailed measurements and scientific understanding of a typical and fully realistic hostile fire, (2) to determine the reproducibility of realistic full-scale room fire tests under optimum control of furnishings and ambient conditions, (3) to test proposed theoretical concepts for generalizing results to other rooms and fuel configurations, (4) to test new experimental measuring instruments (e.g., fan anemometers, bi-directional velocity probes, ray and wide angle radiometers, inexpensive heat flux gauges, smoke property and toxicity devices, etc.), (5) to explore the extensive use of photography for revealing the detailed mechanisms of fire development, and finally, (6) to test sprinkler parameters (water flow, pressure, orifice size) designed specifically for residential occupancies.

This report contains: (1) a detailed description of the test set up and instrumentation, (2) a preliminary comparison with the Second Bedroom Fire Test ('74), (3) a complete tabulation of all data, in engineering units, obtained from all 178 installed transducers as well as pre- and post-test measurements, (4) a critical evaluation of all questionable data, and (5) a detailed chronology of the fire development taken from on site observations and photographic records. Not included here, but readily available, is a large body of source material from the 1975 fire, such as movies, slides, prints, videotapes and IBM compatible computer tapes. The analysis of these results will be reported in Volume II, to be issued about June 1976.

Artyukh, L. Yu., Kaskkarov, V. P., Luk'yanov, A. T., and Sharaya, S. N. "Thermal Regime of Heterogeneous Burning of Solid Fuel," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Artyukh, L. Yu., Vulis, L. A., and Zakarin, E. A. "Numerical Study of a Laminar Gas Flame Jet," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Aslanov, S. K. and Kopeyka, P. I. "Contribution to the Problem of Constructing a Closed Theory of Spin Detonation," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Babaytsév, I. V., Kondrikov, B. N., Sidorov, T. T., and Tyshevich, V. F. "On the Detonability of Some Esters of Nitrous and Nitric Acids," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Babenko, Yu. I. "Some Problems Frequently Encountered in the Theory of Non-stationary Combustion," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Babich, A. P., Belyaev, N. M., and Ryadno, A. A. "Study of the Thermal Explosion of a Heterogeneous System of Two Semi-bounded Bodies," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Babkin, V. S. and V'yun, A. V. "Upper Limit of Flame Propagation with Respect to Pressure in a Bounded Volume," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Baev, V. K., Tret'yakov, P. K., and Yasakov, V. A. "Experimental Determination of the Combustion of Gas-Air Mixtures in a Duct and of Diffusion Combustion in a Parallel Flow at High Velocities," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Bakhtigozin, Sh. Kh., Naumov, M. S., and Shelukhin, G. G. "Calculation of a Turbulent Flame Jet at the Boundary of Parallel Flows," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Baratov, A. N. "Ignition: Flame Propagation, Concentration Limits, Status of the Problem," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Barenblatt, G. I. "Methods of Combustion Theory in Polymer Mechanics," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Barlas, R. A. "Burning of a Suspension at Low Concentrations of the Solid Phase," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Batalova, M. B., Bakhrakh, S. M., and Zubarev, V. N. "Calculation of Detonation Waves in Conical and Cylindrical Charges," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Blinov, V. I., Lushpa, A. I., Khaylov, V. M., and Khudyakov, G. N. "Burning of Rich Kerosene-Air Mixtures in a Tunnel Type Chamber," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Brown, N. J., Fristrom, R. M. (The Johns Hopkins University, Applied Physics Laboratory) **and Sawyer, R. F.** (University of California, Berkeley, California) "A Simple Premixed Flame Model Including an Application to H_2 + Air Flames," *Combustion and Flame 23* 269-275 (1974)

Subjects: Flame model; Model premixed flame; Premixed flame; H_2 + air flames

Authors' Abstract

This communication proposes a tractable, simple model for the prediction of flame velocities and reaction zone properties. Major chemical aspects of the flame are retained, but the spatial flame structure is approximated as a single, uniform reaction zone whose temperature and composition are calculated. Propagation velocity is determined by competition between reaction and transport. The relation

is established by use of a restricted Lewis number approximation applied to the single species, molecular oxygen, and by assuming that diffusion is dominated by the most diffusive species, atomic hydrogen. The resulting algebraic equations are solved for the condition of maximum flame velocity. The model is applied to hydrogen-air flames. Results are compared with experimental measurements and satisfactory agreement is found.

Buckmaster, J. D. (University of Illinois, Urbana, Illinois) "A New Large Damköhler Number Theory of Fuel Droplet Burning," *Combustion and Flame 24* 79-88 (1975)

Subjects: Droplet burning; Damköhler Number for droplets

Author's Abstract

The combustion of a liquid fuel droplet is considered when the Damköhler number is very large, and a solution is constructed that is quite distinct from the Burke-Schumann (B-S) limit. For a certain range of parameters this solution coexists with the B-S limit and is probably unstable. However, there are other values of the parameters for which the new solution exists, but the B-S solution is excluded, and in this case the new solution is probably stable.

Dregalin, A. F., Gruzdeva, Z. Kh., and Lyashev, A. S. "Method of Determining the Errors of the Computational Parameters of the Combustion Process as a Result of Errors in the Thermodynamic Properties of Individual Substances," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Drukovanyy, M. F., Kormin, V. M., and Oberemok, O. N. "Detonation Mechanism of Water Filled Granulated Explosives," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

D'yachenko, N. Kh. and Sviridov, Yu. B. "Combustion Problems in Diesels," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Ezhovskiy, G. K., Mochalova, A. S., and Ozerov, E. S. "Ignition and Combustion of a Magnesium Particle," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Fishbein, J. "Polyurethane Foam," *New Scientist 61* (886) 501 (1974)

Subjects: Foam; Polyurethane; Cigarette test

Safety in Mines Abstracts 23 No. 276
Safety in Mines Research Establishment

The author gives the burning rates of polyurethane foam and allied materials and the level of toxic products when they are burnt. He believes that spontaneous combustion of polyurethane foam is impossible and refers to tests carried out in the United States indicating that the foam can easily be made to pass the required cigarette burn test rate (less than 4 inches per minute).

Frolov, Yu. V., Korotkov, A. I., and Dubovitskiy, V. "Combustion of Mixed Homogenized Systems," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gaynutdinov, R. Sh., Enaleev, R. Sh., and Averko-Antonovich, V. I."Investigation of the Linear Pyrolysis of Material Subjected to a Powerful Stream of Radiant Energy," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Genkin, K. I. and Khazanov, Z. S. "Study of the Mechanism of Combustion in an Engine," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gilinskiy, S. M. and Zak, L. I. "Hypersonic Unsteady Flow of á Burning Gas Mixture Past Bodies of Differing Shape," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gorbunov, G. M. and Khristoforov, I. L. "Mechanism of the Burning Process Behind Front End Assemblies and in the Zone of Inflow of the Secondary Air in the Chambers of Gas Turbine Engines," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gostintsev, Yu. A., Sukhanov, L. A., and Pokhil, P. F. "Nonstationary Processes During the Combustion of Powder," Third All Union Symposium on Combusion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gray, B. F. (University of Leeds, Leeds, England) "Critical Behavior in Chemically Reacting Systems III. An Analytical Criterion for Insensitivity," *Combustion and Flame 24* 43-52 (1975)

Subjects: Thermal explosion theory; Ignition

Author's Abstract

A form of practical stability, based on experimental reproducibility, is defined

and called insensitivity to emphasize the most important physical characteristic shown by chemically reacting systems possessing this property. The necessary and sufficient conditions for the insensitivity of an exothermic first order decomposition reaction are obtained rigorously and it is shown without approximation for the well-stirred case that the maximum subcritical dimensionless temperature rise is unity, regardless of the value of parameter ϵ (the inverse of the dimensionless heat of reaction).

Gremyachkin, V. M. and Istratov, A. G. "Stability of a Plane Flame in a Stream with a Velocity Gradient," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Grishin, A. M. and Kuzin, A. Ya. "Heterogeneous Homogeneous Combustion of a Reacting Plate in a Stream of Oxidizer," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gurevich, M. A., Ozerovan, G. E., and Stepanov, A. M. "Calculation of the Combustion Rate of a Metal Particle Taking Oxide and Condensation into Account," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gusachenko, L. K. "Possibility of Oscillations of Very Low Frequency in a Semi-Closed Volume," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gussak, L. A. "Precombustion Chamber Flame Jet Initiation of Avalanche Activation of Combustion," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gussak, L. A., Samoylov, I. B., Semenov, E. S., Murashov, A. F., Ozerov, E. A., and Stotland, A. I. "The Terminating Stage of Turbulent Burning of a Heterogeneous Mixture," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Hilado, C. J. (Research and Development Department, Union Carbide Corporation) "Flammability Tests, 1975 - A Review," *Fire Technology 11* (4) 282 (1975)

Subject: Flammability tests

Author's Introduction

Flammability tests are, by definition, tests intended to evaluate the flammability characteristics of a material. Flammability characteristics are generally expressed

as numbers generated by flammability tests, because reduction to numerical values facilitates comparisons of materials with each other and with acceptance criteria.

With the increasing concern over fire safety and the growing importance of fire behavior as a factor in market acceptance, flammability tests have increased in number, basked in prominence, and languished in controversy. This review of flammability tests is intended to present them to the reader in perspective and up to date.

Hoshino, M. and Hayashi, K. "Evaluation of Extinguishing Abilities of Fire Fighting Foam Agents for Oil Tank Fires," Report of *The Fire Research Institute of Japan 39* 59 (1975) See Section E.

Itin, V. I., Nayborodenko, Yu. S., Kozlov, Yu. I., and Ushakov, V. P. "Gasless Combustion of a Mixture of Metallic Powders," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Ivanov, B. A., Izmaylov, E. M., Narkuskiy, S. E., Nikonov, A. P., and Pleshakov, V. F. "Limit Conditions of Propagation of Combustion through Metal Specimens in Gaseous Oxygen," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Karpov, V. P. "Reaction of a Flame Front to the Influence of a Shock Wave," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kleymenov, V. V., Mal'tsev, V. M., Seleznev, V. A., and Pokhil, P. F. "Aspects of the Thermodynamic Equilibrium of Combustion Products During Discharge," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Klimov, A. M. "Theory of an Arbitrary Flame Front," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kossoy, A. A., Ozerov, E. S., and Sirkunen, G. I. "Burning of an Evaporating Composite Particle of a Two Component Combustible Containing Metal," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kuzin, A. F., Yankovskiy, V. M., Apollonov, V. L., and Talantov, A. V. "Influence of the Initial Temperature on the Basic Characteristics of Combustion in a

Turbulent Flow of a Homogeneous Mixture," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Lebedev, B. P. and Doktop, I. Yu. "Stabilization of the Flame of Inhomogeneous Mixtures," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Lie, T. T. (Division of Building Research, National Research Council of Canada, Ottawa, Canada) "Characteristic Temperature Curves for Various Fire Severities," *Fire Technology 10* (4) 315 (1974)

Subjects: Temperature curves; Fire severities

Author's Abstract

The temperature curves described here characterize the temperature course of ventilation controlled fires of various severities. They are intended as basic exposure curves for fire resistive design.

Lockwood, F. C. and Naguib, A. S. (Imperial College of Science and Technology, London, England) "The Prediction of the Fluctuations in the Properties of Free, Round-Jet Turbulent, Diffusion Flames," *Combustion and Flame 24* 109-124 (1975)

Subjects: Diffusion flames; Turbulent flames

Authors' Abstract

A physical model is presented for the prediction of the turbulent diffusion flame. In this model the turbulence is represented by differential equations for its kinetic energy and dissipation, equilibrium chemical reaction without intermediates is assumed, standard relations for the thermodynamic properties are applied, a differential equation for the concentration fluctuations is solved, and a 'clipped' normal probability distribution function is proposed for the mixture fraction fluctuations. The final component of the model is particular to the present study. All the individual components of the model are, however, tested, as independently as possible, by comparing predictions with the data for three round, free-jet, turbulent flows: inert and isothermal, inert and nonisothermal, and unpremixed reacting. The agreement between the predictions and the data is, on the whole, very good, but new data are urgently required to permit a more extensive evaluation of the physical modelling.

Manelis, G. B. and Strunin, V. A. "Mechanism of Combustion of Ammonium and Hydrozonium Salts," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Margolin, A. D. "Contemporary Status and Some Problems in the Theory of Combustion of Condensed Systems," Third All Union Symposium on Combustion and Explosion, Leningrad, (June 5-10, 1971) See Section Books.

Mason, W. E. and Saunders, K. V. (Safety in Mines Research Establishment, Harpur Hill, Buxton, Derbys, England) "Recirculating Flow in Vertical Columns of Gas Solid Suspension," *Journal Physics D: Applied Physics 8* 1674 (1975) See Section I.

Nedin, V. V., Neykov, O. D., Alekseev, A. G., Vasil'eva, G. I., and Kostina, E. S. "Study of the Combustion of Gas Suspensions of Metal Powders and of the Influence of Particle Size on the Parameters of Explosiveness," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Ordzhonikidze, S. K., Margolin, A. D., and Pokhil, P. F. "Combustion of Condensed Explosives Under Accelerating Loads," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Paabo, M. and Comeford, J. J. (National Bureau of Standards, Gaithersburg, Maryland) "A Study of the Decomposition Products of Polyurethane Foam Related to Aircraft Cabin Flash Fires," National Bureau of Standards for The National Aviation Facilities Experimental Center, Atlantic City, New Jersey, FAA-RD-73-46 (AD763 327) (July 1973)

Subjects: Decomposition products; Polyurethane foam; Aircraft cabin fires

Abstracted by G. Fristrom

The flash fire potential of polymers of potential interest to the aircraft industry was studied. A laboratory model of a flash fire cell using a high voltage arc as an ignition source was developed. Samples of flexible polyether type urethane foams were pyrolyzed in air, simultaneously measuring the time of onset of a flash fire and withdrawing gas samples for analysis. Flash fires in the cell were recorded on 16 mm motion picture film. Some low molecular weight pyrolysis products were identified. The role of smoke in flash fires was studied.

Palmer, K. N. (Fire Research Station, Borehamwood, England), **Taylor, W., and Paul, K. T.** (Rubber and Plastics Research Association, Shrewsbury, England) "Fire Hazards of Plastics in Furniture and Furnishings: Characteristics of the Burning," *Building Research Establishment Current Paper No. 3* (1975)

Subjects: Furniture fires; Plastic fires; Room fires; Furnishings, combustibility of; Fire hazards of plastics

Authors' Summary

The second year's work of a three year contract on the Fire Hazards of Plastics in

Furniture and Furnishings is described. Comparison has been made of the behavior in fire of furniture and furnishings manufactured from modern materials and of similar items from more traditional materials. The studies of ignition behavior, which were made during the first year of the contract, have led to investigations of the characteristics of burning once ignition has been achieved, and which are the main subjects of the present report.

The burning of individual upholstered chairs and settees, curtains, carpets, beds, and some items manufactured from moulded and rigid plastics foams, was initiated by ignition sources ranging from cigarettes to paper and to wood cribs. Some preliminary full-scale fires in a simulated domestic sitting-room were carried out, and further fires in other types of rooms are being planned. Some supplementary tests on the ignitability of plastics foams are also reported.

In general chairs and settees upholstered with modern materials were ignited by flame considerably more easily than their traditional equivalents. However, as regards the initiation of smouldering by cigarettes, the traditionally upholstered furniture had no advantage. Modern upholstered furniture burned rapidly, with localized high temperatures, whereas the traditional equivalent burned more slowly. Smoke generation was more serious with modern chairs and settees, partly because they burned more rapidly. With modern furniture the wooden frames often remained after the fire, whereas traditional furniture was eventually reduced to ash. Most curtain materials burned readily, giving flames at ceiling level, but materials which melted also gave fires on the floor. Carpet fibers, or underlays, which melted also gave greater fire spread than traditional materials made from natural fibers. Once ignited, the burning of made-up beds was governed by the type of blanket. A woolen blanket gave considerable protection against fire even with flammable mattresses, whereas flammable blankets (cotton, acrylic, polypropylene) led to serious fires with all mattresses tested including interior sprung.

In the limited number of fires carried out with the fully furnished sitting-room the modern furniture ignited readily and burned rapidly, whereas the traditional furniture responded more slowly. However, the burning was controlled by ventilation to the fire, and further tests with different ventilation conditions are required before general conclusions can be drawn. In broad terms, the behavior under fire conditions of small samples of furnishing materials assembled as used in practice, of individual items of furniture, and of furnished sitting-rooms have shown a continuing pattern. The extent to which the behavior of furniture and furnishings in full-scale fires can be predicted from the small-scale experiments with reliability, has still to be measured.

Parker, W. J., Paabo, M., Scott, J. T., Gross, D. and Benjamin, I. A. (National Bureau of Standards, Gaithersburg, Maryland) "Fire Endurance of Gypsum Board Walls and Chases Containing Plastic and Metallic Drain, Waste and Vent Plumbing Systems," *National Bureau of Standards Publication BBS-72,* 114 pp. (September 1975)

Subjects: Fire endurance; Fire spread; Fire tests; Gypsum board; Plastic plumbing; PVC; Smoke

Authors' Abstract

The use of plastic pipe in plumbing systems of multiple-occupancy buildings has raised considerations regarding fire safety. To provide needed data, ten full-scale fire endurance tests were performed involving a total of 39 plumbing chase and wall assemblies containing plastic and metal drain, waste, and vent (DWV) systems typical of installations serving one or two story buildings.

Two tests were conducted using plumbing chase configurations simulating kitchen sink drain systems. The PVC DWV piping in these installations did not contribute to spread of fire from one side of the construction to the other.

Six fire endurance tests were conducted in which the performance of ABS, PVC, copper and iron was compared directly in kitchen sink drain systems as installed in wood-stud and gypsum-board walls. The stacks ranged from 2 inch to 4 inch in diameter and the laterals from 1½ inch to 4 inches. In these tests it was noted that the plumbing configuration and wall construction details, particularly the sealing of plumbing penetrations, seriously affected the fire endurance of the barrier. Satisfactory performance was achieved when certain conditions were met.

In the two tests involving nominal 2 by 4 steel-stud-and-gypsum-board walls it was determined that the one-hour fire resistance rating of the wall was reduced considerably when ABS or PVC DWV was installed within it using the construction details described in this report. These details included back to back 1½-in diameter laterals feeding directly into 2-in diameter stacks.

Panin, V. F., Parfenov, L. K., and Zakharov, Yu. A. "Phenomenon of Three Flame Propagation Limits on the System H_2-O_2-N_2," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Pervitskaya, T. A., Skabin, A. P., and Tarasyuk, V. A. "Approximate Methods of Studying Diffusion Burning in a System of Turbulent Jets," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Potekhin, G. S., Baratov, A. N., Makeev, V. I., Prokhorev, N. S., Pankratov, I. P., and Rozantseva, G. V. "Flegmatization of Detonation and Deflagration Combustion of Kerosene Air and Kerosene Oxygen Systems," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Romanov, O. Ya. and Shelukhin, G. G. "Contribution to the Theory of Stability of Powder Combustion," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Rybanin, S. S. "Theory of the Combustion of Fuel Droplets in a Stationary

Medium and a Flow of Oxidizers," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Salamandra, G. D. "Flame Propagation in a Transverse Electrical Field," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Schmidt, W., Grumbrecht, K., Bohm, H. J., and Blumel, H. "On the Mutual Effect of Open Mine Fires and Ventilation Design," *Gluckauf Forschungsheft 34* (6) 213-220 (1973) (In German)

Subjects: Mine fires; Ventilation

Safety in Mines Abstracts 23 No. 556
Safety in Mines Research Establishment

This is an abbreviated version of a partial report on the research project "Mine air changes and descensional ventilation" for which tests have been carried out at Tremonia Experimental Mine by the Mine Ventilation Testing Station, the Versuchsgrubengesellschaft, and the Central Mine Rescue Station. Here, the theoretical relationships between the parameters involved are discussed critically. Another paper will report later on the tests themselves, their results and evaluation. The aspects studied were the throttle effect of open mine fires, their buoyancy effect, and the combined effect of these two phenomena in conditions of ascensional and descensional ventilation.

Schubert E. and Both, W. "Measures for the Stabilization of Ventilation During Open Mine Fires," *Gluckauf 110* (1) 22-25 (1974) (in German)

Subjects: Mine fires; Ventilation

Safety in Mines Abstracts 23 No. 557
Safety in Mines Research Establishment

Approximately three major open mine fires still occur every year in the Ruhr coalfield. The flow and direction of the ventilation are affected by such a fire and their stabilization is essential for safe guarding the men in the initial stages of the fire and for its control. Suitable measures to this end can be taken on the basis of advance calculations.

Scott, K. A. "Smoke and Toxic Products from Plastics," *RAPRA Journal 1* (11) 282-285 (1973) See Section K.

Selezneva, I. K. "Spherically Symmetrical Optical Discharge as an Analog of Diffusion Combustion in a Fuel Gas Mixture," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Shchetinkov, E. S. "Supersonic Combustion Problems," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Shteynberg, A. S., Ulybin, V. B., Dolgov, E. I., and Manelis, G. B. "Effect of Dispersion in the Processes of Linear Pyrolysis and Combustion of Polymers," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Shevelov, K. K. and Koldunov, S. A. "On the Influence of the Physical State and Structure of Trinitrotoluene Charge in the Decomposition Time in a Detonation Wave," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Solov'ev, V. S., Andreev, S. G., Levantovskiy, A. V., Shamshev, K.N., Fedin, E. D., Tsvetkov, L. P., and Krasov, G. A. "Optical and X-ray Investigations of the Detonation Properties of Low Density Explosives with a Hexogen Base," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Sosnova, G. S. "Combustion of Boron and Aluminum to High Oxides at High Pressure and Temperature," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Stark, G. W. V. and Field, P. (Joint Fire Research Organization, Borehamwood, England) "Toxic Gases and Smoke from Polyvinyl Chloride in Fires in the Fire Research Station Full Scale Test Rig," *Fire Research Note No. 1030*, Joint Fire Research Organization (April 1975) See Section H.

Strokin, V. N. "The Process of Ignition and Combustion of Hydrogen in a Supersonic Flow," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Sulimov, A. A., Obmenin, A. V., Korotkov, A. I., and Shushlyapin, P. I. "Low Velocity Regime of Explosive Transformation in Charges of High Density Solid Explosives," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Tewarson, A. and Pion, R. F. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Burning Intensity of Commercial Samples of Plastics," *Fire Technology 11* (4) 274 (1975)

Subjects: Plastics, burning intensity; Burning intensity of plastics

Authors' Abstract

A novel way of expressing burning intensity has been derived from burning rate data by varying ambient oxygen and applying additional heat flux to the burning samples.

Tyul'panov, R. S., Sokolenko, V. F., and Alimpiev, A. I. "Investigation of the Structure of Hydrogen Diffusion Flames," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Vasil'ev, A. A., Gavrilenko, T. P., and Topchiyan, M. E. "Location of the Chapman Jouguet Surface in a Multifront Detonation in Gases," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Voskoboynikov, I. M. "Decomposition of Hexogen in a Detonation Wave," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Voskoboynikova, N.F. "Critical Detonation Diameters of Solutions of Solid Explosives," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Vulis, L. A. "Turbulent Gas Combustion: Outline of the Present Status of the Theory," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Vulis, L. A., Kuznetsov, O. A., and Yarin, L. P. "Investigation of the Aerodynamics of the Turbulent Flame Jet of a Homogeneous Mixture," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Wiersma, S. J. (Naval Surface Weapons Center, White Oak, Maryland, and Stanford Research Institute, Menlo Park, California) "Characteristics of Fires in Structural Debris," Final Report, July 1973 - January 1975, under Contract DAHC 20-70-C-0300 for The Defense Civil Preparedness Agency (January 1975) See Section D.

Wiersma, S. J. and Martin, S. B. (Stanford Research Institute, Menlo Park, California) "The Nuclear Fire Threat to Urban Areas," Final Report for the

Defense Civil Preparedness Agency under Contract No. DAHC 20-70-C-0219 (April 1975) See Section A.

Williamson, R. B. and Baron, F. M. (University of California, Berkeley, California) "A Corner Fire Test to Simulate Residential Fires," *Journal Fire and Flammability 4* 99-105 (1973)

Subjects: Corner fire test; Residential fires; Fire test

Authors' Summary

We have concluded that the corner test described is useful in determining the fire hazard of some of the newer polymeric building materials. The corner test was used in the past to evaluate the hazard of cellulosic materials and it appears to be a meaningful test procedure. We recommend that a review of all previous corner tests would be a valuable document, and we would be most happy to contribute to this review.

We have primarily used photography to record the tests conducted in our laboratory, but it is clear that certain temperature and heat flux measurements would contribute important information. For instance, it was noted in the work at the Forest Products Laboratory that the temperature of the fire plume six inches below the ceiling was an important indication of the severity of the fire. We believe that the use of measuring instruments should be introduced into the corner test procedures, but we suggest that their meaning would be greatly increased if we had a theoretical understanding of the corner geometry. We understand that this analysis would be difficult, but we urge that it be begun.

Woolley, W. D., Ames, S. A., Pitt, A. I., and Murrell, J. V. (Joint Fire Research Organization, Borehamwood, England) "Fire Behavior of Beds and Bedding Materials," *Fire Research Note No. 1038,* Joint Fire Research Organization (June 1975)

Subjects: Bedding fires; Fire tests

Authors' Summary

Fire tests with measurements of temperatures, radiation levels and smoke production have been carried out using domestic beds fitted with full bedding materials in a full-scale compartment-corridor.

The tests have included mattresses made of polyurethane of various types; hair, spring interior and foamed rubber with mattress covers of cotton, flame retarded cotton or proofed nylon. Some tests with hair or glass fiber cloth protective interlinings are also recorded.

The study has shown that a rapid development of fire in bed and bedding materials can take place with certain combinations of mattresses and their covers. The type of cover is extremely important in the overall fire development, particularly with polyurethane mattresses.

A substantial improvement in the fire behavior of many of the principal types of beds tested can be achieved by a careful selection of bedding materials, such as the type of mattress cover, and in certain cases by the use of protective interlinings.

Yamashita, K. "Laboratory Experiment on Three Dimensional Temperature Profile in the Leeward of Wooden Crib Fire," Report of *The Fire Research Institute of Japan 39* 48 (1975) See Section J.

Zenin, V. I. and Vaynshteyn, B. I. "Particular Features of Manifestation of the Channel Effect in Coarsely Dispersed Explosives," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

H. Chemical Aspects of Fires

Adadurov, G. A., Gustov, V. V., Kosygin, M. Yu., and Yarmol'skiy, P. A. "The Role of Plastic Deformation and the Possibility of Post-Polymerization in the Case of Shock Compression of Acrylamide," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Aldabayev, L. I. and Bakhman, N. H. "Influence of Additions of Solid Oxidizers on the Diffusion Burning of Polymers in Air," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Alekseev, Yu. I., Korolev, V. L., and Knyazhitskiy, V. P. "Measurement of Temperatures During the Linear Pyrolysis of Polymethylmethacrylate," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Azatyan, V. V. and Aleksandrov, E. N. "Study of the Multiple Ignition of Carbon Monoxide under Static Conditions," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Bazhenova, T. V., Lobastov, Yu. S., and Kotlyarov, A. D. "Experimental Investigations of the Dissociation Rate of Water Vapor in Mixtures with Air," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Belyaeva, M. S., Kitaygorodskiy, A. M., and Klimenko, G. K. "Physical Phenomena Occurring in the Initial Stages of Thermal Decomposition of Cyclotrimethylenetrinitramine," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Black, F. M. and Sigsby, J. E. "Chemiluminescent Method for NO and NO_x ($NO + NO_2$) Analysis," *Environmental Science and Technology 8* (2) 149-152 (1974) See Section N.

Bobolev, V. K., Karpukhin, I. A., and Teselkin, V. A. "The Role of Chemical Interaction of Components upon Shock Excitation of an Explosion in Mixtures of Ammonium Perchlorate and Fuel," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Dregalin, A. F., Gruzdeva, Z. Kh., and Lyashev, A. S. "Method of Determining the Errors of the Computational Parameters of the Combustion Process as a Result of Errors in the Thermodynamic Properties of Individual Substances," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Emanuel, N. M. "The Mechanism of Liquid-Phase Oxidation," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Fedotov, N. G., Sarkisov, O. M., and Vedeneev, V. I. "Determining the Probabilities of Heterogeneous and Homogeneous Deactivation of Deuterium Molecules," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Genich, A. P., Levin, V. A., and Osinkin, S. F. "Oxidation of Ammonia in Air Behind a Direct Compression Shock," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Goncharov, E. P., Merzhanov, A. G., and Shteynberg, A. S. "Thermal Decomposition of Condensed Systems at Elevated Temperatures," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gusachenko, L. K. "Possibility of Oscillations of Very Low Frequency in a Semi-Closed Volume," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gussak, L. A. "Precombustion Chamber Flame Jet Initiation of Avalanche Activation of Combustion," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kalabukhov, G. V., Ryzhik, A. B., Yusmanov, Yu. A., Sidorov, V. M., Osipov, B. R., and Faerman, S. N. "Influence of the Reaction Kinetics Properties of an Igniting Flow on the Burning of Aluminum Powders," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kapralova, G. A., Margolina, E. M., and Chaykin, A. M. "Rate Constants of Some Elementary Stages of Fluorine-Hydrogen Reactions," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Karachevtsev, G. V. and Tal'roze, V. L. "Ionic Pressure in a Flame," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Karpinskiy, B. V., Ryabikin, Yu. A., Mansurov, Z. A., Dubinin, V. V., Gershenzon, Yu. M., and Ksandopulo, G. I. "Mechanism of the Effect of Synergism in the Combustion of Hydrogen with Additions of Diethylamine and Tetrafluorodibromoethane," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kim, A. G. and Douglas, L. J. "Gas Chromatographic Method for Analyzing Mixtures of Hydrocarbon and Inorganic Gases," *Journal Chromatographic Science 1973* 615-617 (December 1973)

Subjects: Gas chromatography; Hydrocarbon gases; Inorganic gases

Safety in Mines Abstracts 23 No. 471
Safety in Mines Research Establishment

Gas samples containing oxygen, nitrogen, hydrogen, helium, carbon dioxide, methane, and trace amounts of C_2 to C_5 hydrocarbons are analyzed by a gas chromatographic method that utilizes both thermal conductivity and flame ionization detectors. Porapak and molecular sieve columns are used with argon as the carrier gas. A column selector valve makes it possible to perform a complete analysis either on one 1 ml sample in 40 minutes, or on two 1 ml samples in 20 minutes. Samples are introduced either by on-column injection or through a gas sampling valve. By varying operational parameters, the speed, sensitivity, and accuracy of analysis may be modified.

Klimenko, G. K. and Frolov, E. I. "Particular Features of the Initial Stages of the Low Temperature Decomposition of Ammonium Perchlorate," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Knorre, V. G. and Mamina, N. K. "Investigation of the High-Temperature Inter-

action of Carbon with Oxygen in a Shock Tube," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kochubey, V. F., Moin, F. B., and Shchemelev, G. V. "Study of the Kinetics of Combustion of Mixtures of H_2 and CO," Third Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kondrat'ev, V. N., Popoykova, A. I., and Denisov, E. T. "Collection and Critical Evaluation of Rate Constants of Chemical Reactions," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Koroban, V. A., Chugunkin, V. M., and Loboda, V. I. "Thermal Decomposition of Perchlorates of Methyl Substituted Ammonium Ions," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Koroban, V. A., Svetlov, B. S., and Chugunkin, V. M. "Low Temperature Ammonium Perchlorate Conversion Reactions," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Korobeynichev, O. P., Shkarin, A. V., and Shmelev, A. S. "Catalysis Mechanism in the Thermal Decomposition and Combustion of Ammonium Perchlorate," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Lebedev, S. N., Leonas, V. B., Malama, Yu. G., and Osipov, A. I. "Use of the Monte Carlo Method in Chemical Kinetics," Third All Union Symposium in Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Librovich, V. B. and Makhviladze, G. M. "Propagation of a Low Amplitude Wave Over the Surface of a Powder Burning in a Gas Stream," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Lovachev, L. A. and Gontkovskaya, V. T. "On the Role of Nonlinearity in the Hydrogen Oxidation Scheme," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Losev, S. A. "Study of the Kinetics of Physico-chemical Processes in Shock Tubes," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Marchenko, G. N., Moshev, V. V., Batyr, D. G., Borisov, S. F., and Pogonin, G. P. "Influence of Structural Factors on the Catalytic Activity of β-Diketonates of the 3d Shell Elements in the Thermal Decomposition of Ammonium Perchlorate," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Myers, G. C. and Holmes, C. A. (Forest Products Laboratory, Madison, Wisconsin) "Fire Retardant Treatments for Dry Formed Hardboard," *Forest Products Journal 25* (1) 20-28 (1975) See Section A.

Nesterko, N. A., Taran, E. N., and Tverdokhlebov, V. I. "On the Mechanism of Ion Recombination in a Low Pressure Hydrocarbon Flame," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Novitskiy, E. Z., Ivanov, A. G., and Khokhlov, N. P. "Investigation of the Shock Polymerization of Polymers," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Raevskiy, A. V. and Manelis, G. B. "Development of Reaction Centers in the Thermal Decomposition of Orthorhombic Ammonium Perchlorate and the Role of Dislocations in this Process," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Rubtsov, Yu. I. "Kinetics and Mechanism of Thermal Decomposition of Hydrazonium Salts," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Savintsev, Yu. P., Mulina, T. V., and Boldyrev, V. V. "Mechanism of the Low-Temperature Thermal Decomposition of Ammonium Perchlorate," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Selivanov, V. F., Vlasenko, I. V., Stepanov, R. S., and Gidaspov, B. V. "Principles of the Thermal Decomposition of β-Polynitroalkyamines and Amides," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Semenov, N. N. and Azatyan, V. V. "On the Role of Negative Interaction of Chains and Heterogeneous Reactions of Active Centers during the Combustion of Hydrogen," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Shkadinskiy, K. G. and Khaykin, B. I. "Influence on Heat Losses on Propagation of the Front of an Exothermic Reaction in the Condensed Phase," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Shtern, V. Ya., Revzin, A. F., and Sukhanov, G. V. "Role of Excited Particles in the Acceleration Effect of Additions of Oxygen on the High Temperature Chlorination of Ethylene," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Shtessel, E. A., Averson, A. E., and Pribytkova, K. V. "Influence of Natural Convection on the Ignition of Liquid Explosives," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Stark, G. W. V. and Field, P. (Joint Fire Research Organization, Borehamwood, England) "Toxic Gases and Smoke from Polyvinyl Chloride in Fires in the Fire Research Station Full Scale Test Rig," *Fire Research Note No. 1030,* Joint Fire Research Organization (April 1975)

Subjects: Smoke; Toxic gases; PVC; Polyvinyl chloride; Fire tests; Wood

Authors' Summary

Tests in which the contribution of wall linings of PVC to the fire hazards presented by traditional combustible material (wood) are reported.

PVC linings in a compartment did not significantly change maximum fire gas temperatures, or smoke density, but increased the overall outputs of heat and smoke. Their main contribution was to the toxic gases by the addition of hydrogen chloride to the carbon monoxide from the combustion of wood.

PVC wall paper and cloth did not contribute much to the hazard from a wood fire in a compartment. However, PVC in a corridor could lead to the discharge of larger concentrations of hydrogen chloride.

Svetlov, B. S., Lur'e, B. A., and Kornilova, G. E. "Investigation of the Transformation of Nitrogen Dioxide When It Interacts with Various Organic Compounds in the Condensed Phase," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Woolley, W. D., Fardell, P. J., and Buckland, I. G. (Joint Fire Research Organization, Borehamwood, England) "The Thermal Decomposition Products of Rigid Polyurethane Foams under Laboratory Conditions," *Fire Research Note No. 1039,* Joint Fire Research Organization (August 1975)

Subjects: Polyurethane; Urethanes; Thermal decomposition; Pyrolysis

Authors' Summary

The thermal decomposition of four commercial rigid polyurethane foams (two of which contain organophosphorus flame retardants) has been studied over the temperature range 200 to 1000°C using elemental analysis and gas chromatography.

The general decomposition mechanisms of the foams appear to be similar and involve a preferential release of some of the polyol content followed by a uniform fragmentation of the residue to release particulate material. This particulate material (smoke) appears to volatilize from the furnace zone at temperatures up to 600°C, but decomposes above 700°C to give the typical family of nitrogen containing products of low molecular weight (hydrogen cyanide, acetonitrile, acrylonitrile, pyridine and benzonitrile) as observed with flexible polyurethane foams. The main nitrogen containing product of low molecular weight observed in this work is hydrogen cyanide which increases markedly in yield from 700°C to the maximum temperature studied (1000°C). At 1000°C the yields of hydrogen cyanide from the foams range between 3.8 to 7.3 weight % conversion which represents 28 to 42% of the theoretically available nitrogen.

Yamate, N. and Inoue, A. "Continuous Analyzer for Carbon Monoxide in Ambient Air by Electrochemical Technique," *Kogai To Taisaku 9* (3) 292-296 (1973)

Subjects: Gas analysis; Carbon monoxide

Safety in Mines Abstracts 23 No. 470
Safety in Mines Research Establishment

Describes tests on a commercial automatic environmental carbon monoxide monitoring device, based on an electrochemical measuring principle.

Yakusheva, O. B., Yakushev, V. V., and Dremin, A. N. "Formation of Sulfur Particles in Sodium Thiosulfate Solutions Behind a Shock Front," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Yalovik, M. S. "Dissociation of Molecular Nitrogen in the Absence of Vibrational Equilibrium," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Yampol'skiy, Yu. P., Maksimov, Yu. V., Korochuk, S. I., and Lavrovskiy, K. P. "The Use of Deuterated Compounds to Study the Kinetics and Mechanism of Thermal Conversion of Hydrocarbons," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

I. Physical Aspects of Fires

Abduragimov, I. M., Driker, G. Ya., Ryvkin, A. M., Shvartsman, N. A., and Yantovskiy, S. A. "Inhibition of High and Low Temperature Hydrocarbon Fuel Combustion Reactions," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Adadurov, G. A., Babina, T. V., Breusov, O. N., Drobyshev, V. N., and Pershin, S. V. "On the Relationship between the State of a Material under Dynamic Compression and the Results Obtained when Studying Preserved Specimens," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Adadurov, G. A., Breusov, O. N., Drobyshev, V. N., and Pershin, S. V. "Effect of Shock Waves on a Substance. Phase and Chemical Changes of Niobium Pentoxide," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Alemasov, V. E., Dregalin, A. F., and Cherenkov, A. S. "Calculation of the Composition and Electrical Conductivity of the Heterogeneous Combustion Products of Chemical Fuels," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Aslanov, S. K. and Kopeyka, P. I. "Contribution to the Problem of Constructing a Closed Theory of Spin Detonation," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Baker, W. E., Kulesz, J. J., Ricker, R. E., Bessey, R. L., Westine, P. S., Parr, V. B., and Oldham, G. A. (Southwest Research Institute, San Antonio, Texas) "Workbook for Predicting Pressure Wave and Fragment Effects of Exploding Propellant Tanks and Gas Storage Vessels," Contractor Report NASA CR-134906 for the National Aeronautics and Space Administration (November 1975)

Subjects: Chemical explosions; Explosions, liquid propellants; Explosions, compressed gases; Blast effects

Authors' Abstract

This workbook is intended to provide the designer and the safety engineer with the best available technology that they need to predict damage and hazards from explosions of propellant tanks and bursts of pressure vessels, both near and far from these explosion sources. The information is presented in the form of graphs, tables, and nomographs to allow easy calculation without recourse to difficult mathematical manipulation or the use of extensive computer programs. When complex methods have been used to develop simple prediction aids, they are fully described in appendices.

Topics covered in various chapters are:

(1) Estimation of explosive yield
(2) Characteristics of pressure waves
(3) Effects of pressure waves
(4) Characteristics of fragments
(5) Effects of fragments
(6) Risk assessment and integrated effects.

Short chapters giving discussion of results, conclusions and recommendations for further work are also included.

Bakhrakh, S. M., Zubarev, V. N., and Shanin, A. A. "Shock Waves in Media with Phase Transitions," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Belyaeva, M. S., Kitaygorodskiy, A. M., and Klimenko, G. K. "Physical Phenomena Occurring in the Initial Stages of Thermal Decomposition of Cyclotrimethylenetrinitramine," Third All Union Symposion on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Biryukov, A. S., Dronov, A. P., Kudryavtsev, E. M., Raynin, G. A., and Sobolev, N. N. "Study of a Gasdynamic CO_2 Laser," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Bondar, M. P., Staver, A. M., and Chagelishvili, E. Sh. "Study of the Influence of Solid Inclusions on the Change in Structure and Properties of Two-Phase Alloys under Impact Loading," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Bromberg, K. and Quintiere, J. (National Bureau of Standards, Washington, D.C.) "Radiative Heat Transfer from Products of Combustion in Building Corridor Fires," *Final Report NBSIR 74-596, National Bureau of Standards* (February 1975)

Subjects: Combustion products; Full scale fire; Radiative heat transfer

Authors' Abstract

The contribution of radiative heat transfer from hot combustion products to corridor floors is examined. Data from full-scale corridor fire experiments is used to calculate emissivity and absorptivity of the combustion products. An empirical model based on attenuation by absorption is used to specify the absorption coefficient due to particulates in the products. In these experiments it is shown that radiation from the combustion products is just as significant as radiation from convectively heated walls and ceiling of the corridor. Calculations show that the ratio of radiant heat transfer to the floor due to ceiling emission to that by combustion product emission ranges from about 0.2 to 0.7. Also, molecular gas radiation and particulate radiation can both be significant for the combustion

products. Calculations show that the emissivity of the gaseous combustion products alone would be about 0.3, but the inclusion of soot particles yields an emissivity for the total combustion product mixture of as high as 0.73, based on the experimental data considered.

Dremin, A. N., Kanel, G. I., and Koldunov, S. A. "Study of Spall in Water, Ethyl Alcohol, and Plexiglass," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Fogel'zang, A. E., Adzhemyan, V. Ya., and Svetlov, B. S. "Role of the Reactivity of an Oxidizing Group During the Combustion of Explosive Compounds," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Fortov, V. E. "Construction of the Equation of State of Condensed Media by a Dynamic Experiment," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Gaynutdinov, R. Sh., Enaleev, R. Sh., and Averko-Antonovich, V. I. "Investigation of the Linear Pyrolysis of Material Subjected to a Powerful Stream of Radiant Energy," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Glazkova, A. P. and Andreev, O. K. "Influence of the Nature of Fuel and Catalyst on the Combustion of Mixtures Based on Ammonium and Potassium Perchlorate," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kalinin, A. P., Leonas, V. B., and Sermyagin, A. V. "Kinetic Properties of Gases at High Temperatures: Determination of Collision Integrals," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Karachevtsev, G. V. and Tal'roze, V. L. "Ionic Pressure in a Flame," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kleymenov, V. V., Mal'tsev, V. M., Seleznev, V. A., and Pokhil, P. F. "Aspects of the Thermodynamic Equilibrium of Combustion Products During Discharge," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Kondrikov, B. N. and Sidorova, T. T. "Combustion of Nitrates and Nitrites," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Lapshin, A. I., Lazarenko, T. P., Stupnikov, V. P., and Batsanov, S. S. "On Irreversible Changes in the Properties of Crystallophosphors as a Result of Explosive Action," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Leonard, J. T. and Clark, R. C. (Naval Research Laboratory, Washington, D.C.) "Electrostatic Hazards Produced by Carbon Dioxide in Inerting and Fire Extinguishing Systems," *Final Report, Naval Research Laboratory No. 7920* for The Department of The Navy, Naval Ships Engineering Center (August 1975)

Subjects: Static electricity; Carbon dioxide; Fire suppression; Inerting systems

Authors' Abstract

In tests of the possible electrostatic hazard resulting from the discharge of CO_2 by the hatch-snuffing (inerting) system of gasoline tankers, measurements were made of the field strength developed in a full-scale model of a tanker hatch when a 22.7-kg CO_2 cylinder was discharged via the nozzles of the hatch-snuffing system. A camera employing high-speed film and, in some runs, an instrumented probe were used to detect discharges. The field strength in the center of the hatch reached a maximum value of 50 to 170 kV/m about 40 to 60 s after the CO_2 began to enter the hatch and then fell to zero near the end of the run (120 s). No evidence of electrostatic discharges was found on the photographs or on the oscilloscope traces from the probe circuit. Shipboard tests confirmed the conclusions reached in the model tests.

Companion experiments were also conducted using a 6.8-kg CO_2 fire extinguisher, since this device was involved in a fatal accident. Field strengths of the order of 1300 kV/m were observed when this extinguisher was discharged into a simulated hatch area. Photographs and oscilloscope traces confirmed the presence of electrical discharges. The characteristics of the electrostatic charge generated by the CO_2 hatch-snuffing system differed from the characteristics of the charge generated by the fire extinguisher due to a plastic horn on the extinguisher. The hatch-snuffing system employs eight metal orifices but no horn or similar funneling device. When the plastic horn was removed and the fire extinguisher was discharged through the remaining metal orifice, the field strength was reduced by a factor of 100, clearly demonstrating the charging characteristics of the plastic horn.

Leypunskiy, O. I., Zenin, A. A., and Puchkov, V. M. "Influence of a Catalyst on the Characteristics of the Combustion Zone of a Condensed Substance," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Mason, W. E. and Saunders, K. V. (Safety in Mines Research Establishment, Harpur Hill, Buxton, Derbys, England) "Recirculating Flow in Vertical Columns of Gas Solid Suspension," *Journal Physics D: Applied Physics 8* 1674 (1975)

Subjects: Recirculating flow; Vertical columns; Gas solid suspension

Authors' Abstract

Dust-in-air suspensions were produced by feeding dust into the closed upper end of a long vertical tube, of internal diameter 143 mm, open at the lower end. It was found that the falling dust sets up a recirculating pattern of air flows in the tube, in two distinct cells. In the upper cell, air flows downwards near the tube axis, and upwards near the wall; in the lower cell, air flows downwards in a narrow layer of high dust concentration near the wall, and upwards near the axis. This pattern was observed over a wide range of dust feed rates (from 135 to 420 g min^{-1}), and for tube lengths between 1.5 and 3.75 m; it persisted in the presence of a substantial net air flow down the tube.

Measurements were made of air velocity profiles, dust concentration profiles and pressure variation along the tube; from the results a quantitative picture of the air and dust flows is established, and a mechanism is put forward to account for the two-cell recirculation pattern.

Mineev, V. N., Ivanov, A. G., and Tyunyaev, Yu. N. "Electrical Effects During Shock Compression of Conductive Materials," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Nakakuki, A. "Radiative Heat Transfer to the Burning Liquid and the Vessel from Its Laminar Flame," Report of *The Fire Research Institute of Japan 39* 27 (1975)

Subjects: Pool fires; Liquid fuels; Heat transfer, radiative

Author's Abstract

The radiation heat transfer from the flame to its liquid and vessel wall in the liquid fuel fire was investigated in the laminar flame region. Under the assumption that the radiant heat from the flame is not absorbed in the vapor layer above the liquid surface, the shape factor from a radiation meter to the flame was calculated by a computer. From this shape factor and the irradiance E_1 measured by the radiation meter, the radiant emittance W_1 of the flame was calculated. Using this value of W_1, the radiant heats transferred directly from the flame to its liquid and vessel were obtained, and confirmed to be negligibly small compared with the total heat transferred to the liquid from the flame.

The equations for the shape factors from the flame to its liquid and vessel wall which were derived formerly, are very important for the elucidation of heat transfer mechanism both in the laminar and turbulent flame regions. Therefore, in the appendix of this paper, these shape factors for the flames of special shapes, i.e., the

conical and cylindrical flames were also derived by the customary method and confirmed to agree with the aforementioned equations. Thus, the equations were proved to hold generally.

Nii, R. "Experimental Study on Transportation of High Expansion Foam Through Flexible Ducts," Report of *The Fire Research Institute of Japan 39* 19 (1975) See Section N.

Nikiforov, V. S. and Bakhman, N. H. "Influence of Aluminum Additives on the Effectiveness of an Fe_2O_3 Combustion Catalyst," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Novitskiy, E. Z., Ivanov, A. G., and Khokhlov, N. P. "Investigation of the Shock Polymerization of Polymers," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Novitskiy, E. Z., Tyun'kin, E. S., Mineev, V. N., and Kleshchevnikov, O. A. "Study of Shock-Wave Properties and of Polarization by TsTS-19 Piezoceramics," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Selezneva, I. K. "Spherically Symmetrical Optical Discharge as an Analog of Diffusion Combustion in a Fuel Gas Mixture," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Shteynberg, A. S., Ulybin, V. B., Dolgov, E. I., and Manelis, G. B. "Effect of Dispersion in the Processes of Linear Pyrolysis and Combustion of Polymers," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Strehlow, R. A. (University of Illinois, Urbana, Illinois) **and Baker, W. E.** (Southwest Research Institute, San Antonio, Texas) "The Characterization and Evaluation of Accidental Explosions," *National Aeronautics and Space Administration Report No. NASA CR-134779* under Contract No. NSG 3008 with The University of Illinois (June 1975)

Subjects: Blast waves; Accidental explosions; Blast damage mechanisms; Explosions, ideal and non-ideal

Authors' Abstract

In this review accidental explosions are discussed from a number of points of view. First, all accidental explosions, intentional explosions and natural explosions

are characterized by type so as to form a framework for further discussion. Secondly, the nature of the blast wave produced by an ideal (i.e., point source or H.E.) explosion is discussed to form a basis for describing how other explosion processes yield deviations from ideal blast wave behavior. In this section the current status blast damage mechanism evaluation is also discussed. Thirdly, the current status of our understanding of each different category of accidental explosions is discussed in some detail.

Tesner, P. A., Shraev, B. I., Knorre, V. G., and Glikin, M. A. "Influence of Explosive Decomposition of Acetylene on the Properties of the Resulting Carbon Black," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Thorne, P. F., Theobald, C. R., and Mahendran, P. (Joint Fire Research Establishment, Borehamwood, England) "Pressure Losses in United Kingdom Fire Hose," *Fire Research Note No. 1036,* Joint Fire Research Organization (September 1975)

Subjects: Fire hose losses; Pressure losses in fire hoses

Authors' Summary

Measurements of pressure losses in fire hose and calculated friction factors are reported, and show significant differences between makes of hose. The value for friction factor of 0.005 given in the Manual of Firemanship for all diameters of non-percolating hose is found to be inappropriate for 19 mm hose reel hose and 89 mm hose. Based on the reported measurements, values for these hoses of 0.0065 and 0.007 are more realistic. The high value for 89 mm hose can be attributed to the reduction in diameter of the instantaneous couplings. Coupling losses are also found to be significant in 70 mm hose.

Differences in hose wall construction gave rise to large differences between different makes of 19 mm hose reel hose.

Measurements of hose stretching under pressure are also reported.

Torrance, K. E. and Mahajan, R. L. (Cornell University, Ithaca, New York) "Surface Tension Flows Induced by a Moving Thermal Source," *Combustion Science and Technology 10* 125-136 (1975)

Subjects: Surface tension flows; Marangon effect

Authors' Abstract

Surface tension flows induced by a thermal source moving over an otherwise stationary liquid layer are investigated. Such flows are important for fire spread over flammable liquids at sub-flash temperatures. The flow structure and parameter dependence are obtained with the aid of numerical solutions of the energy and vorticity transport equations in two space dimensions. Convergence of the solutions is established by successively refining the spatial grids. Results are presented for a range of surface tension parameters ($25 \leqslant S \leqslant 250$), Prandtl numbers ($1 \leqslant Pr \leqslant 100$), and Reynolds numbers ($10 \leqslant Re \leqslant 2500$). The Reynolds number

($Re = Uh/\nu$) is based on thermal source speed (U) and layer depth (h). The induced flow takes the form of a captured eddy just below the surface. The rate of fluid circulation in the eddy (dimensional) is found to depend linearly on S, to be essentially independent of Pr, and to be functionally dependent on h. Viscous and boundary-layer flow regimes are found for small and large values of h, respectively, and compare favorably with available analysis.

Tyunyaev, Yu. N., Lisitsyn, Yu. V., Novitskiy, E. Z., Ivanov, A. G., and Mineev, V. N. "Electrical Conductivity of Alloyed and γ-Irradiated NaCl behind a Shock Front," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Vasil'ev, A. A., Gavrilenko, T. P., and Topchiyan, M. E. "Location of the Chapman Jouguet Surface in a Multifront Detonation in Gases," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Vinokurov, A. Ya., Kudryavtsev, E. M., Mironov, V. D., and Trekhov, E. S. "Investigation of Vibrational Relaxation of Carbon Monoxide," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Yakushev, V. V., Nabatov, S. S., and Dremin, A. N. "High-Frequency Methods of Measuring the Dielectric Properties of Condensed Materials behind a Shock Front," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Zakharenko, I. D. and Mali, V. I. "Viscosity of Metals in the Case of Explosive Welding," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Zaslonko, I. S., Kogarko, S. M., Mozzhukhin, E. V., and Demin, A. I. "Vibrational Activation in Exothermic Decomposition Reactions," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

Zhernokletov, M. V. and Zubarev, V. N. "Determination of Isentropes of the Expansion of Substances after Impact Compression," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

J. Meteorological Aspects of Fires

Frost, J. S. and Haines, D. A. (North Central Forest Experimental Station, Saint

Paul, Minnesota) "Fire Weather Stations in North Central and Northeastern United States," *U.S.D.A. Forest Service Research Note NC-194* (1975)

Subjects: Fire danger rating; Fire weather forecasters

Authors' Abstract

This report presents the locations of instrumented fire weather stations that record the data necessary for input into the National Fire Danger Rating System.

Furman, R. W. (Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado) "Estimating Moisture Content of Heavy Forest Fuels," *Forest Science 22* (2) 135-139 (June 1975) See Section A.

Furman, R. W. (Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado) "An Aid to Streamlining Fire Weather Station Networks," *U.S.D.A. Forest Service General Technical Report RM-17* (1975)

Subjects: Fire weather; National Fire Danger Rating System

Author's Abstract

For reasons of economy it may be necessary to close one or several fire-weather stations in a protection area. Since it is logical to close those stations that will have the least impact on the ability of the fire manager to assess overall fire danger, it is desirable to know if there is duplication in monitoring fire climate, and to what degree. A method is proposed for determining this duplication, based on an analysis of six elements of fire climate. Stations are grouped on the basis of similarity of sequences of these fire climate elements over the fire season.

Helfman, R. S., Deeming, J. E., Staub, R. J., and Furman, R. W. (Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado) "User's Guide to AFFIRMS: Time Share Computerized Processing for Fire Danger Rating," *U.S.D.A. Forest Service General Technical Report RM-15* (1975) See Section A.

Mroske, B. E. (Forest Fire Research Institute, Ottawa, Canada) "Development and Utilization of the Model LSC201 Lightning Counter," *Information Report FF-X-54 Canadian Forestry Service,* Department of the Environment, Ottawa, Canada (June 1975) See Section N.

Scholl, D. G. (Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado) "Soil Wettability and Fire in Arizona Chaparral," *Proceedings of The Soil Science Society of America 39* (2) 356 (1975)

Subjects: Soil wettability; Arizona chaparral

Author's Abstract

Soils on typical Arizona chaparral sites showed water repellence both before and after fire. Both field and laboratory fires caused major changes in the water repellency of four natural soil layers. Relatively cool fires caused water repellence in the surface layer, while hot fires produced repellence at a greater depth. Under hot fires, however, the surface layer was rendered completely wettable. By measuring the wetting angle of soil layers from progressively hotter fires, it was possible to pinpoint temperatures where water-repellent layers are first formed and then destroyed. Organic matter decreased at the progressively higher temperatures. Volatilization and subsequent loss to the atmosphere are believed an important part of this loss of organic matter. The volatilized material causing water repellence is almost completely lost above 270°C. Below this temperature, sufficient material is trapped and condensed on exchange sites to produce water repellence.

Taylor, A. R. (Intermountain Forest and Range Experimental Station, Ogden, Utah) "Ecological Aspects of Lightning in Forests," *Proceedings Annual Tall Timbers Fire Ecology Conference,* March 22-23, 1973 p. 455.

Subjects: Lightning; Forests; Ecology

Author's Introduction

Lightning is part of the physical environment of many forest ecosystems throughout the world. Its ubiquity is reflected in Brooks' (1925) estimate that the earth experiences some 44,000 thunderstorms per day and that about 1,800 storms are in progress at any given moment.

According to the U.S. Department of Commerce (1966) these storms produce some 8 million cloud-to-ground discharges each day. If evenly distributed over the earth, about one-half million of them would strike in the world's 4,100 million hectares of forested lands. Recent satellite data collected by Vorpahl et al. (1970) and by Sparrow and Ney (1971) suggest that Brooks' early estimates may have been high and that 10 times as many night storms occur over land as over sea. In any case, lightning strikes thousands of trees around the world each day.

The purpose of this paper is to indicate that lightning has a pervading influence on all trophic levels in the biological community, and that it affects the physical environment as well.

Yamashita, K. "Laboratory Experiment on Three Dimensional Temperature Profile in the Leeward of Wooden Crib Fire," Report of *The Fire Research Institute of Japan 39* 48 (1975)

Subjects: Firewhirls; Plumes; Temperature profiles; Wood; Crib fire(s)

Author's Abstract

In order to elucidate the physical processes of fire spread and formation of fire whirl, a series of laboratory experiments on three dimensional temperature profile

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FIRE RESEARCH ABSTRACTS AND REVIEWS. VOLUME 17, NUMBERS 1-3.(U)

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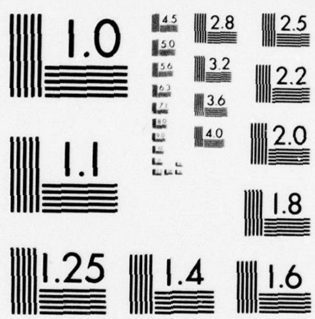

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

of crib fire plume in cross wind was performed. Wooden cribs were ignited by burning some methanol that was sprayed over them at the rate of 2 cm^3/sec within one minute.

About sixty alumel-chromel thermocouples were used to measure the temperature profile in a cross section of fire plume. A tuft screen was also used in the leeward of crib fire to estimate the flow pattern in and around the fire plume.

Under the experimental conditions with several combinations of wind velocity, crib width, ground roughness, number of fire and so on, three dimensional temperature profile of fire plume especially in the cross section normal to wind direction was obtained.

Both trajectories of fire plumes and temperature decay on them were expressed as a function of the ratio of momentum flux of flame to wind. Equi-temperature contours in the cross section normal to wind were also obtained.

From the experimental result, it became evident that a fire in cross wind produces a pair of vortex-like circulation in the downstream side of fire plume, and the temperature contours in the cross section normal to wind take a horse-shoe shape probably due to the circulation induced by fire.

K. Physiological and Psychological Problems from Fires

Dressler, D. P., Skornik, W. A., Bloom, S. B., and Dougherty, J. D. (Harvard Medical School, Cambridge, Massachusetts and Trans World Airlines, New York, New York) "Smoke Toxicity of Common Aircraft Carpets," *Aviation, Space and Environmental Medicine 46* (9) 1141-1143, (1975)

Subjects: Smoke toxicity; Aircraft carpets

Authors' Abstract

The smoke toxicity of three carpets commonly available for use in commercial aircraft was determined by ignition in a specially designed smoke apparatus. Rats were exposed for 15 min to three different fuel loads, on a weight-to-volume basis. Evaluation was by mortality, time of useful function (TUF), and unconsciousness. No deaths were noted with carpets A or C at 64 mg/*l* or 128 mg/*l* fuel load concentration: at 256 mg/*l*, 42% mortality resulted from carpet A and 4.5% with carpet C. Exposure to carpet B resulted in a mortality of 4.3%, 72.5%, and 100% at the three concentrations. The TUF data and time of unconsciousness correlated closely with the results of the mortality, but were much more sensitive. These studies indicate that a potential severe hazard exists with some types of carpet, and further research is needed to identify and eliminate these materials from aircraft interiors.

Edginton, J. A. G. and Lynch, R. D. (Chemical Defence Establishment, Porton Down, Salisbury, England) "The Acute Inhalation Toxicity of Carbon Monoxide from Burning Wood," *Fire Research Note No. 1040*, Joint Fire Research Organization (August 1975)

Subjects: Toxicity, CO, from wood; Carbon monoxide; Wood

Authors' Summary

The acute inhalation toxicity to rats and guinea pigs of carbon monoxide as a pure gas, or as evolved during the controlled burning of two different plywoods has been measured. There were significant, though very slight, differences. The slightly greater toxicity with the plywood exposures was probably due to changes in the respiratory minute volume produced by the irritants in the wood pyrolysis products, although this is unproven.

Einhorn, I. N. (University of Utah, Salt Lake City, Utah) "Physiological and Toxicological Aspects of Smoke Produced During the Combustion of Polymeric Materials," *Environmental Health Perspectives 11* 163-189 (1975)

Subjects: Smoke, physiological aspects; Smoke, toxicological aspects; Combbustion; Polymeric material combustion

Author's Abstract

Normally one expects that flame contact is the major cause of injury and death during fires. Analysis of the factors involved in numerous fires has revealed that most deaths were not due to flame contact, but were a consequence of the production of carbon monoxide, nitrogen oxides, and other combustion products, such as aldehydes, low molecular weight alcohols, hydrogen cyanide, and other noxious species.

The major emphasis within the scope of this paper relates to the physiological and toxicological aspects of smoke produced during the combustion of materials. Special emphasis is directed toward laboratory procedures which have been developed to determine the qualitative and quantitative analysis of smoke, factors pertaining to smoke development, and to measure the response of laboratory animals exposed to smoke. The effects that fire retardants, incorporated into polymeric materials as a means of improving flammability characteristics, may have on smoke development, the mechanism of polymer degradation, and on the survival response of laboratory animals are also considered.

Fire Protection Review, "Interbuild Conference on Fire Risk of Plastics," *Fire Protection Review 37* (398) 25 (1974)

Subjects: Interbuild conference; Fire risk; Plastics, fire risk

Safety in Mines Abstracts 23 No. 49
Safety in Mines Research Establishment

Review of papers presented by delegates to a conference ("Plastics - an increasing fire risk") organized by the Building Research Establishment and held in London on November 16, 1973. Papers were read on the subjects of present and future trends in the use of plastics, the fire performance of plastics in building applications and the reduction of hazards in the use of plastics.

Junod, T. L. (Aerospace Safety Research and Data Institute, Cleveland, Ohio) "Toxic Substances Alert Program," Technical Memorandum NASA TM X-71711, National Aeronautics and Space Administration, 117 pp. (April 1975)

Subjects: Toxicity; Toxic substances

Author's Abstract

This is a description of the Toxic Substances Alert Program at the Lewis Research Center and contains a profile of each of the 102 toxic substances procured during a recent 12 month period. The goal of the Toxic Substances Alert Program is to ensure that the health and safety personnel are aware which toxic substances are being used and to alert and inform the users as to their toxic characteristics. The program provides a continuing record of the toxic substances being procured, who has procured them, what other toxic substances the user has obtained in the past and where similar materials have been used elsewhere at the Center.

Pal, K. "Toxic Effects of the Combustion Gases of Polymers," *Muanyag es Gumi 11* (2) 48-52 (February 1974) (in Hungarian)

Subjects: Toxic effects, polymer combustion gases; Polymer combustion; Gases from polymer combustion

Safety in Mines Abstracts 23 No. 482
Safety in Mines Research Establishment

A survey is made of current knowledge of the toxic effects of gases and smoke produced by burning polymers. Gases and smoke produced by PVC and by nitrogen containing polymers (PAN, polyamides, polyurethane, urea formaldehyde resin) are dealt with in more detail.

Scott, K. A. "Smoke and Toxic Products from Plastics," *RAPRA Journal 1* (11) 282-285 (1973)

Subjects: Smoke; Toxic products; Plastics

Safety in Mines Abstracts 23 No. 48
Safety in Mines Research Establishment

The author considers some of the current developments in test procedures for smoke and toxic products. Methods reviewed are: The Swedish Hot Box; The Dutch flash over test; ASTM D 2843/70; BS 476:Pt. 9.

Stark, G. W. V. and Field, P. (Joint Fire Research Organization, Borehamwood, England) "Toxic Gases and Smoke from Polyvinyl Chloride in Fires in the Fire Research Station Full Scale Test Rig," *Fire Research Note No. 1030*, Joint Fire Research Organization (April 1975) See Section H.

L. Operations Research, Mathematical Methods, and Statistics

Albini, F. A. (Intermountain Forest and Range Experiment Station, Ogden, Utah) "A Computer Algorithm for Sorting Field Data on Fuel Depths," *U.S.D.A. Forest Service General Technical Report INT-23* (1975)

Subjects: Fuel depth (forest); Forest fuels, depth data

Author's Abstract

This report describes an algorithm for separating depth measurements of forest fuels into distinct groups. Presented is a flow chart and Fortran listing. Copies of the computer program are available from the author.

Charkov, V. P., Egorov, V. A., Brusentsev, G. K., and Shul'ga, Yu. N. "Influence of the Starting Time of the Extinguishing Operation of Exogenous Fires on the Duration and Method of Extinction," *Ugol' Ukr. 17* (7) 40-41 (1973) (in Russian)

Subjects: Extinguishment; Extinction time; Exogenous fires; Extinction

Safety in Mines Abstracts 23 No. 193
Safety in Mines Research Establishment

It has been established that there is an increase in the number of prolonged exogenous fires and the time to put them out. An analysis has been made of two hundred cases of exogenous fires and from the statistical data a relationship between the delay in the start of extinguishment and extinction time has been developed.

Deeming, J. E. (Rocky Mountain Forest and Range Experiment Station, Boise, Idaho) **and Brown, J. K.** (Intermountain Forest and Range Experiment Station, Missoula, Montana) "Fuel Models in the National Fire Danger Rating System," *Journal Forestry 73* 347-350 (1975)

Subjects: Fuel models; National Fire Danger Rating System; NFDR

Authors' Abstract

Fuel models were developed to provide data required by the mathematical fire behavior model which is the basis for the spread and energy release components of the National Fire Danger Rating (NFDR) System. The fuel models quantitatively describe those physical and chemical properties of fuel elements and fuel beds that govern flammability. Thus far, nine models representing broad vegatative types have been developed for rating fire danger.

Dormont, P., Hausner, J., and Walker, W. E. "Firehouse Site Evaluation Model: Description and User's Manual," The New York City Rand Institute for the

Department of Housing and Urban Development, *Report No. R-1618/2-HUD* (June 1975)

Subject: Firehouse site model

Authors' Summary

This report describes a computer-based model, called the Firehouse Site Evaluation Model (or "siting model"), that can be used to evaluate alternative configurations of fire-fighting companies. The siting model provides a way to estimate the fire protection levels, measured in terms of travel times, travel distances, and company workloads, that would result from implementation of any given arrangement of fire companies. By comparing the fire protection levels resulting from one arrangment with those resulting from others, rational decisions can be made about the deployment of a city's fire companies.

The report is organized so that persons with different interests in the siting model can read the appropriate sections without having to read the entire report. The earlier sections are designed to be read by fire department planners and systems analysts. They provide information about how and when to use the model, the model's assumptions, and the input to and output from the model. An illustration of how the model was used to analyze fire company deployment in Trenton, New Jersey, is also included. The latter sections of the report are designed for the data processing personnel who will be installing and maintaining the siting model. They include a program listing, a description of the input data, sample printouts, and detailed instructions for installing the model.

Fire Protection Journaux Officiels, Paris, 598 pp. (August 1973) (in French)

Subjects: Fire protection; Control of fires

Safety in Mines Abstracts 23 No. 53
Safety in Mines Research Establishment

Collection of official texts, decrees and laws concerning general legislation and regulations for public buildings, high buildings, apartment blocks, and industrial and commercial establishments in matters relating to fire protection.

Haines, D. A., Johnson, V. J., and Main, W. A. (North Central Forest Experiment Station, Saint Paul, Minnesota) "Wildfire Atlas of the Northeastern and North Central States," *U.S.D.A. Forest Service General Technical Report NC-16* (1975)

Subjects: Fire danger rating; Fire season, national forest

Authors' Abstract

Describes patterns of forest fire activity across the northeastern and north central United States. Gives average dates of greening and curing of herbaceous plants,

median size of fires in various fuels, and annual profiles of peak fire activity. It also examines combinations of major fire cause and day-of-week activity.

Helfman, R. S., Deeming, J. E., Staub, R. J., and Furman, R. W. (Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado) "User's Guide to AFFIRMS: Time Share Computerized Processing for Fire Danger Rating," *U.S.D.A. Forest Service General Technical Report RM-15* (1975) See Section A.

Heller, D. "A New Comprehensive Solution to the Problem of the Detection of an Explosive Hazard: The Dräger Exwarn G 1," *Draeger Hft.* (292-293) 10-14 (April-September 1973) (in German) See Section N.

Kissel, F. N., Nagel, A. E., and Zabetakis, M. G. "Coal Mine Explosions: Seasonal Trends," *Science 179* 891-892 (March 1973)

Subjects: Dust explosions; Gas explosions; Mine explosions; Coal

Abstracted by G. Fristrom

Disaster reports on coal mine explosions were analyzed. Gas explosions were found to be randomly distributed throughout the year. Dust explosions, including those triggered by gas explosion, occurred more frequently during the fall and winter. Dry cold weather tended to increase the rate and severity of dust explosions.

Lie, T. T. (National Research Council Canada, Ottawa, Canada) "Probabilistic Aspects of Fire in Buildings," National Research Council Canada, *Division of Building Research Technical Paper No. 422* (June 1974)

Subjects: Probabilistics; Fire in buildings; Building fires

Author's Abstract

A method is given by which the loss expectation for buildings, both the life loss expectation and the property loss expectation, can be determined. The use of the loss expectation as a criterion that can quantitatively express the degree of fire safety that is provided in a building is discussed. It is shown how, in principle, fire protection measures can be optimized and how various parameters affect the optimum measures.

This study is an extension of previous work.

"Measurement of Smoke Density, Flammability, and Toxic Gases," *PRT Polymer Age 4* (54) 140 (1973)

Subjects: Smoke; Combustion products; Oxygen index

Safety in Mines Abstracts 23 No. 47

Safety in Mines Research Establishment

At a conference held in the Spring of 1973 in Queen Mary College on "Smoke from burning plastics" it was implied that measurement of smoke, gases and allied combustion products was not yet technically feasible except by the use of very expensive equipment. This article refutes this statement and describes two pieces of equipment designed for the investigation of flammability as expressed by the Critical Oxygen Index (COI), smoke density, temperature and rate of burning, afterglow as measured by a thermocouple system, and the development and analyses of gases.

National Transportation Safety Board, Washington, D.C. "Pipeline Accident Report - Atlanta Gas Light Company, Atlanta, Georgia, August 31, 1972," *National Transportation Safety Board Report NTSB-PAR-73-3* (PB 223 336) 26 pp. (August 1972)

Subjects: Pipeline accident; Atlanta Gas Light Company; Explosion

Safety in Mines Abstracts 23 No. 41
Safety in Mines Research Establishment

This report describes and analyzes a gas explosion which occurred shortly after 9 a.m. on August 31, 1972, in the annex building of an Atlanta, Georgia, high school. Gas had leaked into the building from a cracked cast-iron main located beneath the street in front of the annex. Atlanta Gas Light Company (AGL) personnel arrived at the leak site approximately 1 hour after AGL was first notified of the leak and approximately 1/2 hour before the explosion. One person died and seven others were injured as a result of the accident. The National Transportation Safety Board determines that the probable cause of the explosion was the ignition of gas that leaked from a cast-iron main cracked by uneven soil settlement which applied a bending force to the pipe in an area weakened by graphitization. Contributing to the explosion was the failure by the gas company to check for gas in the building, to shut off the flow of leaking gas, and to notify police and fire officials. The report contains recommendations to the Office of Pipeline Safety of the Department of Transportation, the American Society of Mechanical Engineers Gas Piping Standards Committee, and the Atlanta Gas Light Company. The recommendations concern, among other items, OPS accident-reporting requirements, nationwide compliance with Federally required written emergency procedures, factors involved in cast-iron pipe failures, and the effect of graphitization on cast-iron mains.

National Transportation Safety Board, Washington, D.C. "Pipeline Accident Report - Exxon Pipe Line Company, Crude Oil Explosion at Hearne, Texas, May 14, 1972," *National Transportation Safety Board Report NTSB-PAR-73-2* (PB-222 656) 18 pp. (August 1973)

Subjects: Pipeline accident; Exxon pipe line; Crude oil explosion, Hearne, Texas

Safety in Mines Abstracts 23 No. 39
Safety in Mines Research Establishment

This report describes and analyzes the explosion, on May 14, 1972, of crude oil vapors which had sprayed from a ruptured 8-inch pipeline operated by the Exxon Pipe Line Company near Hearne, Texas. The explosion was followed by a fire, which killed one person, seriously burned two others, destroyed a house, and melted nearby railroad, telephone, and pipeline communications lines. The National Transportation Safety Board determines that the probable cause of the explosion and fire was the ignition of an accumulation of crude oil vapors which had sprayed from a shutdown, closed-in pipeline which had ruptured by excessive internal pressure. Contributing to the failure of the pipe was its thin-wall condition, caused by corrosion of the unprotected bare steel walls. The report contains recommendations to the Office of Pipeline Safety of the Department of Transportation and the Exxon Pipe Line Company. The recommendations to OPS concern hydrostatic testing of old lines and the clarification of 49 CFR 195.408, "Communications". The recommendations to Exxon concern steps which should be taken for safer operation of this and other Exxon pipelines.

Powell, J. H. (Safety in Mines Research Establishment, Sheffield, England) "Assessment of the Maintenance of the Effectiveness of Safety Schemes by Inspection and Age Replacement of Protective Devices," *Journal Institute Maths Applics 16* 81-92 (1975)

Subjects: Maintenance of safety devices; Safety schemes; Inspection protective device; Protective device replacement

Author's Abstract

Expressions are derived for quantities measuring deficiencies occurring in the protective capabilities of safety schemes comprised of devices which are subject to random failure. The devices are assumed to be prone to two modes of failure, one which is readily detectable in service, and one which is undetectable in service. The expressions take into account the effects of preventive maintenance procedures in which devices are inspected at regularly spaced times to discover and renew devices which have failed "detectably," and also devices are replaced after a specified age in service to mitigate the effects of "undetectable" failures. These expressions are evaluated for devices having constant failure rate (i.e., exponential failure distributions) for both modes of failure; and also for a constant "detectable"-failure rate and an increasing "undetectable"-failure rate (i.e., represented by a second order gamma function failure distribution).

Rider, K. L. "A Parametric Model for the Allocation of Fire Companies," The New York City Rand Institute for the Department of Housing and Urban Development *Report No. R-1615-NYC/HUD* (April 1975)

Subject: Fire companies allocation

Author's Summary

A major problem facing the management of most municipal fire departments is the allocation of fire-fighting companies among the various regions of their city. For example, in New York City the Fire Department would like to be able to concentrate its companies in the areas of greatest alarm activity, such as the South Bronx. However, it cannot provide substandard service to the lower alarm rate areas of the city, such as Staten Island. Therefore, trade-offs exist that must be recognized and coped with.

A fire department has two goals that determine the manner in which its fire-fighting resources are deployed: an actual service must be provided when demanded, and the service must be available for potential need. The first goal provides little difficulty since the number of units physically required to fight fires at any one time is relatively small. Service availability, however, is more difficult to deal with objectively. While 90% of a city's fire-fighting resources may be idle at any one time, when they are needed they are needed quickly. To a great extent, therefore, any fire company allocation criterion will be closely related to the availability of service. While it may be assumed that a fire department, under the constraint of a fixed budget, will try to balance the availability of its services throughout the city in an equitable manner, this concept is difficult to translate into an operational policy. The pursuit of such a goal requires the integration of several often-conflicting objectives. For example, is the average fire loss in the city to be minimized or is the risk of loss to be spread evenly over the city?

This report describes an allocation method that avoids the difficulty of predetermining a specific criterion. Instead the method allows the decisionmaker to enumerate a complete range of criteria by varying a trade-off parameter. In practice, it will often be the case that all but a small subset of these criteria will result in allocations with consequences that are unacceptable to fire department management.

The allocation model developed in this report provides an explicit trade-off parameter. The model uses travel time as a measure of system performance and generates allocations satisfying criteria ranging from the minimization of city-wide travel time to the equalization of average regional travel times as the trade-off parameter varies. While neither of these two criteria will necessarily produce satisfactory deployment policies, it may be expected that some policy between these two extremes will be reasonable. The Parametric Allocation Model therefore uses an objective function that encompasses, by the change of a single parameter, both of these criteria and all intermediate criteria.

In the course of constructing the model, some basic system measures are defined: *busy density* is the hourly alarm rate per unit area weighted by average worktimes at alarms; *hazard factor* is the relative rate at which an average fire in a region grows; and *availability density* is the average number of companies per unit area available for service. The mathematical model is formulated as a minimization problem and solved using the technique of Lagrange multipliers. The solution for the number of companies, n_i^*, to assign to region i is

$$n_i^* = \mu_i^* A_i + b_i \ ,$$

where

$$\mu_i^* = \rho_i^{\nu} \eta_i^{1-\nu} N(\nu).$$

The variables in the solution are defined as follows:

A_i is the area of region i; b_i is the average number of companies busy in region i (given by the hourly alarm rate times average worktime);
μ_i^* is the resulting availability density in region i;
η_i is a function of the hazard factor in region i;
ρ_i is the busy density in region i;
ν is an adjustable trade-off coefficient;
$N(\nu)$ is a normalizing factor.

The solution as a function of ν can be seen as a trade-off between the realized demand represented by ρ_i and the potential hazard represented by η_i. ρ_i is composed of such factors as the total company time it takes to put out a fire, the number of fires in a region, etc.; η_i is composed of travel rates, the rate of possible fire spread, etc. An examination of the form of the solution leads to several observations that can be useful in developing deployment policies. If two regions of a city have identical busy density and hazard factor, the allocation of available companies should be in proportion to their areas regardless of the value of ν. If these two regions are combined and their areas added together, the allocation to the new region is the sum of the allocations to the old regions. Therefore, a homogeneous region can be split into several parts without changing the total allocation. If two areas of unequal busy density are combined, the resulting allocation will be greater than if the allocation were made to these areas separately (therefore, to ensure that the regions are homogeneous, it is better to use smaller areas for aggregating fire data and making allocations.)

A comparison of the allocations generated by the model with the 1973 allocation of fire companies in New York City shows that one value of the trade-off parameter ν produces results that correspond closely to the 1973 allocation policy. This is a compromise policy in which the average city-wide travel time is close to its minimum, while the largest average regional travel time is substantially lower than if the minimum average travel time criterion were used.

Shanesy, C. "An On-line Program for Relocating Fire Fighting Resources," *The New York City Rand Institute R-1506-NYC* (June 1975)

Subject: Fire fighting resources

Author's Summary

This Report describes a computer program that allows a fire dispatcher to monitor fire protection in his jurisdiction on a real-time basis. Based on equipment status entered by the dispatcher, the program informs him when coverage in some area is unsatisfactory and how to move equipment to correct the situation. This Report contains complete information for operating the program and extensive

examples of its use based on a sample data base drawn from the Borough of the Bronx in New York City.

The Report also includes (1) instructions for preparing the data required to use the program in any geographic area, (2) a description of the logical flow of the program, (3) definitions of variables used in the program, (4) program modifications, and (5) program listings.

Walker, W. E. "Performing Policy Analysis for Municipal Agencies: Lessons from the New York City - Rand Institute's Fire Project," *The New York City Rand Institute Report No. P-5426* (April 1975)

Subject: Municipal policy analysis

Author's Abstract

The New York City-Rand Institute was involved in performing policy analysis for the New York City Fire Department over a period of 7½ years. During this time many changes were made in the Fire Department's operations based largely on the results of the Institute's analysis. This paper discusses some of the changes, proposes some explanations for the success of the project, and describes how the work led to a similar effort to perform deployment policy studies for emergency service agencies throughout the country under federal sponsorship. The paper concludes with some impressions about what the work has taught us about performing urban policy analysis for operating agencies and transferring technology to municipal government personnel.

N. Instrumentation and Fire Equipment

Alvares, N. J., Kanury, A. M., Wiersma, S. J. (Stanford Research Institute, Menlo Park, California) **and Pefley, R. K.** (University of Santa Clara, California) "Firesafe Sanctuaries for High-Rise Structures," *Fire Technology 11* (4) 241 (1975)

Subjects: Firesafe sanctuaries; High-rise structures

Authors' Abstract

Using extensively available information on heat transfer, construction methods, ventilation, and human transient thermal response, the authors demonstrate the feasibility of the concept of firesafe sanctuaries for high-rise structures.

Bergman, I. (Safety in Mines Research Establishment, Sheffield, England) "Electrochemical Carbon Monoxide Sensors Based on the Metallised Membrane Electrode," *Annals Occupational Hygiene 18* 53-62 Pergamon Press (1975) See Section C.

Black, F. M. and Sigsby, J. E. "Chemiluminescent Method for NO and NO_x (NO + NO_2) Analysis," *Environmental Science and Technology 8* (2) 149-152 (1974)

Subjects: Gas analysis; Oxides of nitrogen; Chemiluminescent analytical methods; NO and NO_x analysis

Safety in Mines Abstracts 23 No. 252
Safety in Mines Research Establishment

An instrumental method has been developed which will permit rapid, sensitive measurement of nitric oxide (NO) and oxides of nitrogen (NO_x = NO + NO_2) by chemiluminescent techniques. NO is measured by photoelectric amplification of a signal produced by the chemiluminescent reaction of NO and ozone. NO_x is measured by photoelectric amplification of a signal produced by the chemiluminescent reaction of NO_x and atomic oxygen. The atomic oxygen is produced by gas phase thermal decomposition of ozone.

Brenden, J. J. (Forest Products Laboratory, Madison, Wisconsin) "Apparatus for Measuring Rate of Heat Release from Building Materials," *Journal Fire and Flammability 6* 50 (1975)

Subjects: Heat release; Building materials; Combustibility of materials

Author's Abstract

In defining "combustibility" of building materials, code officials have considered measuring this property in relation to total heat content. A better method of defining "combustibility" could be measuring the "rate of heat release," the time-rate at which the heat of combustion is released. A gas-fired, water-jacketed furnace and auxiliary equipment designed to measure the rate of heat release of an 18- by 18-inch specimen under controlled flaming conditions is described. Various means by which the equipment can be operated and the rate of heat release computed are included.

Breuer, H., Robock, K., Stuke, J., and Schliephake, R. W. "Perfecting a Gravimetrical Instrument for Routine Sampling," Proceedings of the Conference on Technical Measures of Dust Prevention and Suppression in Mines, 11-13 October, 1972, Luxembourgh, European Communities Commission 153-164 (1973)

Subjects: Dust sampling; Gravimetrical instrument

Safety in Mines Abstracts 23 No. 125
Safety in Mines Research Establishment

The following devices were developed by Bergbau-Forschung, Essen, for a routine measurement method: 1. the gravimetric dust sampler TBF 50 with two cyclones connected in series, by means of which the fine dust undergoing pulmonary deposition is separated in the second cyclone. The throughput of air of 50 litres/minute enables the fine dust sample necessary for x-ray determination of quartz to be collected in one shift. 2. for rationalizing a central evaluation

unit - a semi-automatic quartz determination with special measuring equipment, - automatic weighing equipment which weighs fully automatically a set of 95 samples, and produces the results on punched tape, - an indirect method of ash determination. 3. The dust photometer for the continuous monitoring of the dust concentration at points where heavy dust development occurs, and as a portable measuring instrument for short-period measurements. The value of scattered light intensity measured with this instrument corresponds to the dust deposited in the lung alveoli.

Chironis, N. P. "New Instrument Controlled Vehicles May Soon Improve Safety in Mines," *Coal Age 78* (12) 52-57 (1973)

Subjects: Mine safety; Mine fires; Remote control vehicles; Vehicles, remote control

Safety in Mines Abstracts 23 No. 190
Safety in Mines Research Establishment

The U.S. Bureau of Mines is sponsoring the construction of several remote-controlled vehicles which are described in this article: 1. an experimental vehicle for fire-fighting, incorporating a TV camera and a water hose fire extinguisher, guided from a remote control panel to which the vehicle returns. The vehicle also carries transducers to pick up and transmit data on heat and noxious gases and a night-vision camera. 2. A shuttle car that is driven by instruments that collect and analyze reflecting waves. 3. A laser-guided continuous miner that allows a miner to operate along a true course by simply watching a dial.

Courbon, P. "Dust Weight Sampling," Proceedings of the Conference on Technical Measures of Dust Prevention and Suppression in Mines, 11-13 October 1972, Luxembourgh, European Communities Commission 165-178 (1973)

Subjects: Dust suppression; Dust weight sampling

Safety in Mines Abstracts 23 No. 124
Safety in Mines Research Establishment

Only one granulometric fraction of the particle in suspension in a dusty atmosphere is liable to enter and remain in the alveoli. Referring to Hatch's curve of alveolar deposition and to the various interpretations of this, the author reviews the main sampling instruments and describes a new one - the CPM3. This has a rotating filter of polyurethane foam, has a flow rate of 3 m^3/h and weighs 2.5 kg. It is intrinsically safe.

Croce, P. A. (Factory Mutual Research Corporation, Norwood, Massachusetts) "A Method for Improved Measurement of Gas Concentration Histories in Rapidly Developing Fires," *Factory Mutual Research Corporation Technical Report 21011.3 RC75-TP-29* under Grant NSF-G134734 for The National Science Foundation (July 1975)

Subjects: Analysis of fire gases; Fire gas concentrations; Rapidly developing fires

Author's Abstract

A method is described for improving the transient gas concentration measurement in a relatively fast-developing fire or in any changing environment with a characteristic transient time that is comparable to the response time of the sampling system (including analyzer). Under such conditions, the measurements can be significantly altered in both time and magnitude and, hence, be of limited usefulness. The method utilizes the result of a simple laboratory test - the response of the measuring system to a step input - to determine the sampled concentration history from the analyzer record.

Cybulski, W. "Studies of Triggered Barriers," Fifteenth International Conference of Safety in Mines Research, Karlovy Vary, Czechoslovakia, 13 pp. (September 1973) See Section A.

Depew, C. A., Mann, M. J., and Corlett, R. C. "A Laboratory Simulation of Wood Pyrolysis Under Field Conditions," *Combustion Science and Technology 6* (4) 241-246 (1972)

Subjects: Pyrolysis; Wood products

Authors' Abstract

The disposal of logging slash by burning is an important forest management tool. This paper describes a laboratory simulation of wood pyrolysis under field burning conditions, in which the thermal environment experienced by burning fuel elements can be arbitrarily controlled. This apparatus is capable of imposing ranges of incident radiant flux and ambient air flow rate for a cylindrical wood specimen. Outputs are the specimen weight loss rate and particulate air pollutant production rate. For the results reported here, the fuel was Douglas fir dowelling, both plain and treated with the flame retardant "Phos-Chek," principally diammonium phosphate. Observed combustion patterns tend to become independent of fuel conditions and retardant treatment at relatively high environmental temperatures. At lower temperatures, combustion patterns are difficult to reproduce, and are very sensitive to flame retardant treatment. On the basis of the limited data so far available, no evidence has been found that flame retardant treatment under otherwise controlled conditions results in reduction of air pollutants.

Fung, F. C. W. (National Bureau of Standards, Gaithersburg, Maryland) "Smoke Control by Systematic Pressurization," *Fire Technology 11* (4) 261 (1975)

Subjects: Smoke control; Pressurization for smoke control

Author's Introduction

A series of full-scale smoke movement experiments were conducted by the National Bureau of Standards in selected high-rise buildings using a sulfur hexafluoride tracer technique for smoke simulation. Among the buildings selected for study were the thirty-six-story Seattle Federal Building and the forty-two-story Chicago Federal Building. Both have provisions for switching the air handling system in the building to an emergency mode for smoke control. These experiments were designed to study the effectiveness of this new smoke control system.

Heller, D. "A New Comprehensive Solution to the Problem of the Detection of an Explosive Hazard: The Dräger Exwarn G 1," *Draeger Hft.* (292-293) 10-14 (April-September 1973) (in German)

Subjects: Explosion detector; Detector of explosion

Safety in Mines Abstracts 23 No. 37
Safety in Mines Research Establishment

The instrument is automatic, makes continuous measurements of combustible gases and vapors, and gives an automatic acoustic or optical alarm signal; the measuring range is 0-50% of the lower ignition limit, with the alarm threshold at 20% of the lower ignition limit. The design of the instrument which uses pellistors as measuring elements and is battery-driven, and the method of measurement are described.

Hoshino, M. and Hayashi, K. "Evaluation of Extinguishing Abilities of Fire Fighting Foam Agents for Oil Tank Fires," Report of *The Fire Research Institute of Japan 39* 59 (1975) See Section E.

Johnson, L. D., Canfield, J. A., Lull, D. B., and Morris, T. F. "The Development of a System to Suppress and Extinguish Fully Developed Coal Dust Explosions: Progress Report," *Naval Weapons Laboratory, Technical Report NWL-TR-3030,* Dahlgren, Virginia 140 pp. (September 1973)

Subjects: Mine explosions; Chemical extinguishants; Coal dust

Abstracted by R. Fristrom

A Bureau of Mines program to develop a coal mine dust explosion suppression system has obtained results. After a study of coal dust explosions a plan was developed, a test facility built and several suppression devices tested. The facility is a 4.5 foot diameter shock tube, 317 feet in length. Fifty-three tests have been carried out with methane air and methane coal dust air explosive mixtures. Suppression of slow (up to 300 ft/sec) flame fronts has been successful in two tests using Purple K ($KHCO_3$). Delivery of the material into the flame front seems required for effective suppression.

"Lightweight Breathing Apparatus" *Mining Magazine 130* (1) 47 (January 1974)

Subject: Breathing apparatus

Safety in Mines Abstracts 23 No. 59
Safety in Mines Research Establishment

High-purity oxygen is supplied to miners affected by smoke, gas and dust from a new 4-lb breathing apparatus which will sustain them for at least one hour of strenuous physical labor. Carbon dioxide breathed out through one tube is absorbed by a canister of potassium superoxide. The oxygen released into the breathing bag is inhaled through the second tube to the bite-type mouthpiece. The miner thus breathes only oxygen released from the chemical.

Mroske, B. E. (Forest Fire Research Institute, Ottawa, Canada) "Development and Utilization of the Model LSC201 Lightning Counter," *Information Report FF-X-54 Canadian Forestry Service,* Department of the Environment, Ottawa, Canada (June 1975)

Subjects: Lightning detection; Counter for lightning; Thunderstorm tracking

Author's Summary

The Model LSC201 counter possesses the basic attributes required for an electronic lightning counter as part of a system to predict the occurrence of lightning-caused forest fires. In addition, the LSC201 features portability, an asset which will result in it replacing the Pierce counter as the basis of a thunderstorm tracking network. It is necessary, however, to be aware of its limitations and the guidelines which pertain to the installation of the new counter.

Nii, R. "Experimental Study on Transportation of High Expansion Foam Through Flexible Ducts," Report of *The Fire Research Institute of Japan 39* 19 (1975)

Subjects: Foam, flow; Flow losses, of foam, in ducts

Author's Abstract

There are very little data concerning losses in pressure and in flow rate during transportation of high expansion (hi.-ex.) foam through ducts.

A few studies done of the transportation of hi.-ex. foam, however, are still not enough for the technical information, especially on the blowing conditions or the foam generating one.

Accordingly, a series of experiments about transportation of hi.-ex. foam through flexible ducts were performed by the author with a hi.-ex. foam generator in which a turboblower was used; and which was newly manufactured in the workshop of our Institute, and with another hi.-ex. foam generator in which a multiblade fan is used; and which was previously manufactured in the same workshop. The expansion ratio of foam used at each experiment run was 200 to 750. The extension of duct was done mostly by multiplying connections of a spiral duct

which is 5 m in length, 30 cm in inner diameter, and made of vinylon tarpaulin with a PVC coating.

Furthermore, some trials for some increase of transportable distance of hi.-ex. foam were done by means of some duct arrangements with a Y-shaped duct and some straight ducts between two blowers, one of which is used for hi.-ex. foam generator, and the other one of which is only for foam transportation.

From the experimental results, following conclusions were obtained.

The static pressure loss per unit length of ducts p was defined by

$$p = P_s / L$$

where L is the maximum transportable distance of the foam through the duct in meters, and P_s is the constant saturated static pressure in mmAq at the inflow-end of foam stream. In the duct in the range of L, a continuous foam stream can be kept up, and the ratio of mean cross section of continuous foam stream to the cross section of the duct is equal to about 0.45.

The optimum expansion ratio for transportation of hi.-ex. foam was 400 to 500. The pressure loss p at the optimum expansion ratio was about 1.0 mmAq/m for a horizontally straight or not so sharply curved duct (with $p/d > 10$. where p is a radius of curvature of duct arranged and d is a duct diameter). The pressure loss p of a foam whose expansion ratio is 750, is about twice that of the optimum one.

It can be presumed that the transportable distance of hi.-ex. foam in the vertical direction is decreased by about half that of the horizontal one, judging from a good coincidence of the sectional area of continuous foam stream at a vertical distance with that at the horizontal distance which is equal to about twice the vertical distance.

For a hi.-ex. foam generator of small capacity, e.g., the air volume rate is less than 100 m^3/min and the max. static pressure is less than 50 mmAq, it is possible to increase a transportable distance by means of connection of a Y-shaped duct to the suitable blower on one edge and to the foam generator on another edge, provided that the mean air velocity in duct on the side of hi.-ex. foam generator is always smaller than that on the side of the blower for foam transportation only, and that a duct arrangement in the transporting direction of foams is almost a straight line.

Sato, A. (Chubu Institute of Technology, Kasugai, Japan), **Hashiba, K., Hasatani, M., Sugiyama, S.** (Nagoya University, Nagoya, Japan) **and Kimura, J.** (Toho Gas Company, Nagoya, Japan) "A Correctional Calculation Method for Thermocouple Measurements of Temperatures in Flames," *Combustion and Flame 24* 35-41 (1975)

Subjects: Thermocouples; Flame temperature; Temperatures

Authors' Abstract

A new correctional calculation method is proposed for measurements of temperature profiles in flames with a thermocouple. This method includes an iterative procedure of correcting a temperature profile with respect to conductive and radiative heat losses.

Experiments were performed on hydrogen-air and town gas-air flames. Three different sized thermocouples (0.1, 0.3 and 0.5 mm in dia.) were introduced and the temperature profiles were measured. The real temperature profiles were computed according to those data. The corrected profiles were in agreement with each other.

Furthermore, the accuracy of this correctional method is discussed by taking into consideration the influence of several parameters on heat transfer.

Thorne, P.F., Theobald, C. R., and Mahendran, P. (Joint Fire Research Organization, Borehamwood, England) "Pressure Losses in United Kingdom Fire Hose," *Fire Research Note No. 1036*, Joint Fire Research Organization (September 1975) See Section I.

White, K. J. and Reynolds, R. W. (U.S.A. Ballistics Research Laboratories, Aberdeen Proving Ground, Maryland) "Apparatus for Detecting Interior Ballistic Combustion Products," *Memorandum Report No. 2497, U.S. Army Material Command*, Alexandria, Virginia, 34 pp. (July 1975)

Subjects: Ignition; Combustion; Propellants; Molecular beam; Mass spectroscopy

Authors' Abstract

A molecular beam sampling system has been developed for the purpose of studying transient chemical species produced in the interior ballistic combustion process. The system consists of four differentially pumped vacuum stages with a time-of-flight mass spectrometer used as a detector. Maximum flexibility was considered in the design, especially with respect to the reactor operating pressure. It is believed the reactions can be studied in the pressure range of a few torr up to 5000 psi. A number of factors that went into the design will be discussed such as pumping capacity requirements, boundary layer problems, minimum reaction time calculations, minimum sensitivity, mass separation problem, mass cracking pattern for radicals and excited species, non-vibrational equilibrium problems, formation of initial jet, Reynolds number consideration, choice of skimmer cone angle, mass clustering problem, background penetration, beam quality analysis with such techniques as velocity profile, avoidance of shock formation at various stages, and finally the choice of a well known chemical system on which to test the apparatus.

Some initial studies will involve the decomposition flames of ethyl nitrate and n-propylnitrate.

Yakushev, V. V., Nabatov, S. S., and Dremin, A. N. "High-Frequency Methods of Measuring the Dielectric Properties of Condensed Materials behind a Shock Front," Third All Union Symposium on Combustion and Explosion, Leningrad (June 5-10, 1971) See Section Books.

O. Miscellaneous

Alexander, M. E. and Hawksworth, F. G. (Rocky Mountain Forest and Range

Experimental Station, Fort Collins, Colorado) "Wildland Fires and Dwarf Mistletoes: A Literature Review of Ecology and Prescribed Burning," *U.S.D.A. Forest Service General Technical Report RM-14* (1975)

Subjects: Wildfires; Prescribed burning; Fire ecology

Authors' Abstract

Wildfires play a multiple role in the distribution of dwarf mistletoes — they may either inhibit or encourage these parasites depending primarily on the size and intensity of the burn. Many reports suggest that fire exclusion policies of the past half century have resulted in increased dwarf mistletoe levels as well as increased fire behavior potential. Prescribed burning as a supplemental method of dwarf mistletoe control has been little used, but seems to be applicable in some forest types and stand conditions both to eliminate infected residuals in cutover areas and to eliminate heavily infested unmerchantable stands. Suggested areas of research relating to fire ecology and prescribed burning are given.

Fowler, L. C. (Joint Fire Research Organization, Borehamwood, England) "Collected Summaries of Fire Research Notes 1974," *Fire Research Note No. 1034,* Joint Fire Research Organization (April 1975)

Subject: Fire Research Notes

Author's Abstract

These summaries were prepared for the Fire Offices' Committee of the Joint Fire Research Organization. Fire Research notes published in 1974 are summarized.

Giles, K. and Powell, P. (National Bureau of Standards, Washington, D.C.) "Attacking the Fire Problem: A Plan for Action," *National Bureau of Standards Special Publication NBS-416,* Programmatic Center for Fire Research 42 pp. (May 1975)

Subject: Fire problem

Authors' Abstract

The mission of the Center for Fire Research is to insure the development of standards and specifications needed in support of the national goal to reduce fire losses by 50% over the next generation. A systems approach to accomplish this mission is described. The Center consists of three basic programs in the area of fire science and five applied research programs in the area of fire safety engineering. Each applied program addresses an aspect of the fire problem, using fundamental information supplied by the basic research function. Active participation by staff members in voluntary standards organizations is the principal means of making this technology available for codes and standards needed to reduce the Nation's fire loss.

Heins, C. F. (Denver Research Institute, University of Denver, Colorado) "A Case Study of Technology Transfer: Fire Safety," for The Technology Utilization Office under Contract No. NASW-2607, National Aeronautics and Space Administration (April 1975)

Subjects: Fire safety; Technology transfer

CONTENTS

I. An Overview of the Fire Safety Field.
II. NASA Contributions to the Development of Fire Safety Products and Systems.
III. NASA Contributions to the Development of Fire Safety Standards and Procedures.
IV. A Comment on Transfer Issues.

Junod, T. L. (Aerospace Safety Research and Data Institute, Cleveland, Ohio) "Toxic Substances Alert Program," Technical Memorandum NASA TM X-71711, National Aeronautics and Space Administration, 117 pp. (April 1975) See Section K.

Ludtke, P. R. (National Bureau of Standards, Boulder, Colorado) "Register of Hydrogen Technology Experts," *Final Report NASA CR-2624* under Contract No. NASA Order C-21352-C for The National Aeronautics and Space Administration (October 1975)

Subjects: Hydrogen technology; Hydrogen technology experts; Hydrogen safety

Author's Abstract

This register presents the names of approximatly 235 individuals who are considered experts, or very knowledgeable, in various fields of technology related to hydrogen. Approximately 90 organizations are represented. Each person is listed by organizational affiliation, address, and principal area of expertise. The criteria for selection of names for the register are extensive experience in a given field of work, participation in or supervision of relevant research programs, contributions to the literature, or being recognized as an expert in a particular field. The purpose of the register is to present, in easy form, sources of dependable information regarding highly technical areas of hydrogen technology, with particular emphasis on safety. The register includes two indexes: an alphabetical listing of the experts and an alphabetical listing of the organizations with which they are affiliated.

North Central Forest Experiment Station Annual List of Publications 1974, North Central Forest Experimental Station, Saint Paul, Minnesota

Fire Section

Brown, J. K. and Roussopoulos, P. J. "Eliminating Biases in the Planar Intersect Method for Estimating Volumes of Small Fuels," *Forest Science 20* (4) 350-356 (1974) See Section A.

Crosby, J. S. and Loomis, R. M. "Some Forest Fuelbed Characteristics of Black Oak Stands in Southeast Missouri," U.S.D.A. Forest Service Research Note NC-162, 4 pp. (1974)

Donoghue, L. R. "Prescribed Burning in the Central Lake States - 1972," U.S.D.A. Forest Service Research Note NC-170, 2 pp. (1974)

Haines, D. A. and Main, W. A. "Methods in Constructing a Fire Atlas," *American Meteorological Society Bulletin 55* (1) 72 (1974)

Loomis, R. M. "Predicting the Losses in Sawtimber Volume and Quality from Fires in Oak Hickory Forests," U.S.D.A. Forest Service Research Paper NC-104, 6 pp. (1974)

Loomis, R. M., Crandall, C. R., and Mullavey, R. E. "New York Reduces Railroad Fires," U.S.D.A. *Forest Service Fire Management 35* (2) 3 (1974)

Main, W. A. "Sensitivity of the National Fire Danger Rating System to Change in Herbaceous Vegetation Condition," *American Meteorological Society Bulletin 55* (1) 71 (1974)

Main, W. A. and Haines, D. A. "The Causes of Fires on Northeastern National Forests," U.S.D.A. Forest Service Research Paper NC-102, 7 pp. (1974)

Roussopoulos, P. J. "An Application of the Fire Danger Model in Fuel Hazard Management," *American Meteorological Society Bulletin 55* (1) 70 (1974)

Pierovich, J., Clarke, E., Pickford, S., and Ward, F. (Pacific Northwest Forest and Range Experiment Sation, Portland, Oregon) "Forest Residues Management Guidelines for the Pacific Northwest,"*U.S.D.A. Forest Service General Technical Report PNW-33* (1975)

Subjects: Forest residues; Forest residue treatment; Residue management; Prescribed burning

Authors' Abstract

Forest residues often require treatment to meet land management objectives. Guideline statements for managing forest residues are presented to provide direction for achieving these objectives. The latest research information and the best knowledge of experts in various land management disciplines were used to formulate these statements. A unique keying system is provided for determining which

guidelines apply to a particular management activity, for a given site in a given location, and within a given forest species association type.

BOOKS

Halogenated Fire Suppressants, Editor R. G. Gann, *American Chemical Society Symposium Series 16*, American Chemical Society, Washington, D.C. (1975)

Subjects: Fire suppressants; Halogenated fire suppressants

Publishers' Summary

A symposium hosted by the
Southwest Research Institute, San Antonio, Texas

The need exists for a conveniently local, non-destructive, physiologically tolerable fire suppressant. Although the three major halogenated suppressants in commercial use today fill this need in many respects, they post potential hazards.

Fifteen papers examine the basic processes occurring in inhibited flames and deduce mechanistic elements for suppressing fires by halons. The chapters review prior classical and contemporary bulk flame inhibition studies, describe various studies of chemically and dynamically different flame-halon systems, review the current state of the pertinent kinetics, and attempt to gather, model, and interpret previously presented data. Topics cover halons 1301, 1211, and 2402, development of standards, the antimony-halogen system, halomethane and nitrogen quenching an opposed jet stabilized flame, methane flames, the hydrogen-oxygen reaction, initial reactions in flame inhibition, halogen kinetics, a physical suppression mechanism, and the role of ions and electrons. Many of the chapters are followed by a short discussion, and a general panel discussion is included after the last chapter.

CONTENTS

Preface

1. An Overview of Halon 1301 Systems - C. L. Ford
2. The Relevance of Fundamental Studies of Flame Inhibition to the Development of Standards for the Halogenated Extinguishing Agent Systems - M. J. Miller
3. CF_3Br Suppression of Turbulent, Class B Fuel Fires - N. J. Alvares
4. Mechanistic Studies of Halogenated Flame Retardants: The Antimony Halogen System - J. W. Hastie and C. L. McBee
5. Effect of CF_3Br on Counterflow Combustion of Liquid Fuel with Diluted Oxygen - K. Seshadri and F. A. Williams
6. Halomethane and Nitrogen Quenching of Hydrogen and Hydrocarbon Diffusion and Premixed Flames - R. F. Kubin, R. H. Knipe, and A. S. Gordon
7. The Effect of Halogens on the Blowout Characteristics of an Opposed Jet Stabilized Flame - R. W. Schefer, N. J. Brown, and R. F. Sawyer

8. Effects of CF_3Br on a $CO-H_2-O_2-Ar$ Diffusion Flame - L. W. Hunter, C. Grunfelder, and R. M. Fristrom
9. The Effect of CF_3Br on Radical Concentration Profiles in Methane Flames - J. C. Biordi, C. P. Lazzara, and J. F. Papp
10. Inhibition of the Hydrogen Oxygen Reaction by CF_3Br and CF_2BrCF_2Br - G. B. Skinner
11. Initial Reactions in Flame Inhibition by Halogenated Hydrocarbons - R. G. Gann
12. Halogen Kinetics Pertinent to Flame Inhibition: A Review - N. J. Brown
13. Halogenated Fire Extinguishants: Flame Suppression by a Physical Mechanism? - E. R. Larsen
14. The Role of Ions and Electrons in Flame Inhibition by Halogenated Hydrocarbons: Two Views - E. T. McHale and A. Mandl
15. Theoretical Investigation of Inhibition Phenomena in Halogenated Flames - S. Galant and J. P. Appleton

General Discussion

Roytman, M. Ya. *Principles of Fire Safety Standards for Building Construction,* Construction Literature Publishing House, Moscow 1969, Published for the National Bureau of Standards, Department of Commerce by Amerind Publishing Company Pvt. Ltd., New Delhi (1975)

Subjects: Fire safety; Building standards; Building construction, fire safety

Publishers' Summary

The author has attempted to generalize the research work carried out by various institutions and organizations. Also, an effort has been made to review the experience of other countries with fire prevention codes.

Although reference is made to foreign practices in this book, the main content has been drawn from domestic experience. The purpose of this book is to point out the scientific basis of building design and planning to ensure the safety of people in buildings and to suggest methods for standardizing fire safety practices.

The results of scientific research conducted by planning and design organizations and agencies of the USSR State Fire Service for the development of basic fire prevention building codes have been generalized in this book. Approximate methods for calculating the actual and required fire resistance ratings of structures have been included, as well as methods for determining the cross sections of smoke and explosion vents and the structural designs of smoke shafts and blow-out panels. Design experience with fire barriers has been generalized, and the necessary separation distances between buildings and other structures for the purpose of preventing fire spread are specified. Building design requirements for safe evacuation of people and methods for calculating permissible and actual evacuation time are described.

This book can be used by designers and architects, fire prevention officials, fire service trainees, and structural engineering students.

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Proceedings of Symposium on Air Quality and Smoke from Urban and Forest Fires, October 24-26, 1973, Committee on Fire Research, Commission on Sociotechnical Systems, National Research Council, National Academy of Sciences, Washington, D.C. (1976) Chairman J. S. Barrows

Program

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Panel Discussion: Priorities for Smoke Research - Moderator C. Chandler (U.S. Forest Service)

"Smoke Composition" - J. R. Smith and J. C. Suggs (U.S. Environmental Protection Agency)

"Fuels - The Source of the Matter" - H. E. Anderson (U.S. Forest Service)

"Smoke and Forest Fire Behavior" - D. E. Williams (Canadian Forestry Service)

Panel Discussion: Government and Industry Programs for Smoke Control - Moderator W. R. Tikkala (U.S. Forest Service)

"The National Forest View" - H. W. DeBruin (U.S. Forest Service)
"State Forestry Programs for Smoke Control" - R. C. Winkworth (State Forester, North Carolina)
"U.S. Department of Interior Programs for Smoke Control" - J. H. Richardson (Bureau of Land Management)
"Industry Programs for Smoke Control in Forest Management" - S. R. Miller (The Chesapeake Corporation of Virginia)
"The California Air Resources Board Program to Regulate Agricultural Burning" - J. J. Morgester (California Air Resources Board)

Proceedings of Third All Union Symposium on Combustion and Explosion, Leningrad, June 5-10, 1971, Science Press, Moscow 1972, Editor in Chief L. N. Stesik.

Abstracts translated by L. Holtzschlag. Abstracts listed alphabetically by author.

Abduragimov, I. M., Driker, G. Ya., Ryvkin, A. M., Shvartsman, N. A., and Yantovskiy, S. A. "Inhibition of High and Low Temperature Hydrocarbon Fuel Combustion Reactions," 712-715

Sections: E, I, B

Subjects: Inhibition; Hydrocarbons; Combustion; Ignition: $C_2F_4Br_2$; Kinetics

The influence of dibromotetrafluoroethane inhibitors and of bromine-containing hydrocarbons of the methane series on the combustion of aviation fuels, benzene and propane was investigated. The self-ignition temperature was found to be dependent on the concentration of $C_2F_4Br_2$. The self-ignition region for TS-1 and T-1 fuels was determined. The presence of a cold flame was established for these fuels at atmospheric pressure. The dibromotetrafluoroethane affects the high temperature reactions 1½ times more effectively than the low-temperature reactions. This is explained partially by its thermal decomposition. The constant of monomolecular decomposition of $C_2F_4Br_2$ [$10^{12.55}$ exp $(-52{,}500/RT)sec^{-1}$] was determined, as well as the constants of its effective decomposition reaction in the presence of oxygen and propane.

Abrukov, S. A., Isayev, N. A., and Maksimov, Yu. Ya. "Study of the Influence of Electric Fields on Flame Stabilization and Oscillation," 313-317

Section: G

Subjects: Electric fields; Flame stabilization; Flame oscillation

The influence of a constant electric field on the stabilization and oscillation of C_3H_8, CO, and H_2 flames is investigated. It is shown that the influence is uniquely dependent on the strength and is governed by the experimental conditions. The influence of the field on flame stabilization and oscillation is a unique function of the current passing through the flame. On the basis of the experimental data and schlieren photographs of the flame in an electrical field, it is concluded that flame

stabilization is explained by recirculation of the hot gases by the ion wind. The influence of the electric field on flame oscillation is also explained by the ion wind mechanism.

Adadurov, G. A., Babina, T. V., Breusov, O. N., Drobyshev, V. N., and Pershin, S. V. "On the Relationship Between the State of a Material Under Dynamic Compression and the Results Obtained When Studying Preserved Specimens," 523-528

Section: I

Subjects: Compression state; Diffusion; Crystal growth; Phase transitions; Pressure, high

Ideas as to the unusually high rates of growth of new-phase crystals in shock waves, the unusually high diffusion coefficients, and other features of processes under shock compression are analyzed. It is concluded that the speed of the phase transformations in shock waves is due not to the increase in the linear rate of growth of the new phases, but to the sharp increase in the number of crystallization centers.

Adadurov, G. A., Breusov, O. N., Drobyshev, V. N., and Pershin, S. V. "Effect of Shock Waves on a Substance. Phase and Chemical Changes of Niobium Pentoxide," 540-543

Section: I

Subjects: Shock waves; Phase changes; Niobium pentoxide

The action of dynamic pressures of 65 to 1800 kbars amplitude on low-temperature orthorhombic and high-temperature monoclinic modifications of niobium pentoxide are studied. It is shown that as a result of shock compression of these modifications cross transformations are observed. It is found that compression of niobium pentoxide to pressures of 1500 kbars without a change in composition permits us to achieve a unique transition from the pentoxide structure to a tetragonal structure of the rutile type, which is characteristic under normal conditions for niobium dioxide. A number of disordered non-stoichiometric phases of Nb_xO_2 ($0.8 \leqslant x \leqslant 1.0$) is obtained with structure of the rutile type; in this way we obtained a range of continuous solid solutions including dioxide and pentoxide in their composition.

Adadurov, G. A., Gustov, V. V., Kosygin, M. Yu., and Yarmol'skiy, P. A. "The Role of Plastic Deformation and the Possibility of Post-Polymerization in the Case of Shock Compression of Acrylamide," 529-532

Section: H

Subjects: Plastic deformation; Shock compression; Acrylamide; Polymers

It is shown that non-one-dimensional plastic deformations lead to an increase in

the number of polymer chains and in the yield of the polymer compared to compression of acrylamide under conditions not complicated by appreciable plastic deformations. Using a multi-layer assembly, a relationship is obtained between the yield of the polymer and the compression amplitude between 1% and 17% compression. At a degree of deformation of about 1% the dependence of the yield of the polymer on the initial temperature of compression is found. The hypothesis that the yield of the polymer under shock compression with an initial temperature of -196°C is due primarily to the aftereffect. It is shown that thermal polymerization of shock-compressed acrylamide leads to an increase in the yield of the polymer. It is proposed that the passage of the shock wave brings about activation of the material with a subsequent polymer chain growth reaction.

Afanas'ev, G. T., Bobolev, V. K., and Dolgov, V. I. "Contribution to the Theory of Mechanical Initiation of Solid Explosives," 504-510

Section : B

Subjects: Explosives; Mechanical initiation; Ignition; Detonation

Using a previously proposed mechanism of the formation of local heating and assuming a Pi-shaped profile of the temperature in the source, the authors show that the dependence of the critical tension on the size of the zone of destruction is always decreasing. Considered from this viewpoint is the influence of the dimensions of the active body, the charge, and its inhomogeneities on the excitation parameters of the explosion, and a quantitative estimate of the sensitivity for mechanical effects is refined with respect to an open volume. To determine the exact values of the critical stresses, two methods are proposed and experimental results are presented. The nature of subsonic (low-velocity) regimes of explosive transformation, propagating through dense charges, in shells stronger than explosives, at velocities greater by several orders than the velocity of normal combustion, is clarified.

Aldabayev, L. I. and Bakhman, N. H. "Influence of Additions of Solid Oxidizers on the Diffusion Burning of Polymers in Air," 132-136

Sections: G, H

Subjects: Polymers; Diffusion burning; Solid oxidizers, additions

Considered is the transition from diffusion burning of PMM in air to burning of a mixture of PMM and ammonia perchlorate (PA) by way of the oxidizer itself. It is shown that the introduction of additions of PA to PMM increases the burning rate of PMM appreciably. For PMM-PA mixtures containing up to 40-50% of PA, the combustion in air takes place in two stages. First a portion of the pure PMM burns, followed by ignition of a portion of the PA-PMM mixture (the composition of which corresponds to the upper limit of combustion concentration), then the cycle repeats several times. PMM-PA mixtures containing more than 60-75% of

PA (depending on its degree of dispersion) burns by way of the oxidizer proper. In the intermediate region burning is unstable. A simple theoretical model of two-stage burning is proposed, making it possible to calculate the burning rates of similar compositions. Also proposed are formulas for calculating the flash ignition frequency.

Alekseev, Yu. I., Korolev, V. L., and Knyazhitskiy, V. P. "Measurement of Temperatures During the Linear Pyrolysis of Polymethylmethacrylate," 128-131

Sections: G, H

Subjects: Polymethylmethacrylate; Linear pyrolysis; Temperature measurement during pyrolysis

Problems connected with variation of the temperature field in the condensed and gas phases are examined by means of micro-thermocouples. It is found that near the surface of pyrolysis the thermocouple protruding from the specimen is coated with a K-phase layer. This factor invalidates the results of measurements in the condensed phase. It is noted that such a phenomenon is observed for all forms of thermocouples used.

It is established that carbon compounds condense on a thermocouple passed through the jet of a diffusion flame. This leads to appreciable errors in measuring the temperature distribution. Rapid application and withdrawal of the thermocouple leads to a considerable decrease in the curve. It is shown that radiative heat losses explain with sufficient clarity the discrepancy between the results.

Alemasov, V. E., Dregalin, A. F., and Cherenkov, A. S. "Calculation of the Composition and Electrical Conductivity of the Heterogeneous Combustion Products of Chemical Fuels," 430-434

Sections: I, G

Subjects: Combustion product composition; Electrical conductivity; Heterogeneous combustion

A description is given of methods developed for calculating the composition of heterogeneous mixtures taking into account ionization of the condensed phase. Computational relations are presented for determining the electrical conductivity of heterogeneous ionized products. The computer programs are briefly characterized. The influence of variation in the work of the electron yield from the condensed particle and of its radius on the composition of the heterogeneous mixture is examined using as example the fuel pair liquid-oxygen + kerosene (oxidizer-fuel ratio $\alpha = 1$) with an addition of 15% aluminum.

Artyukh, L. Yu., Kaskkarov, V. P., Luk'yanov, A. T., and Sharaya, S. N. "Thermal Regime of Heterogeneous Burning of Solid Fuel," 137-141

Section: G

Subjects: Thermal regime; Heterogeneous combustion; Solid fuel

Given are the results of an approximate analytical and numerical investigation of the problem of heterogeneous combustion. The reaction rate depends on the temperature according to the Arrhenius law and is of the first order in oxidizer concentration. A study is made of the influence of the temperature and concentration of the oxidizer in the medium, the radiation, and natural convection on the thermal combustion regime.

Alemasov, V. E., Dregalin, A. F., Gruzdeva, Z. Kh., and Lyashev, A. S. "Method of Determining the Errors of the Computational Parameters of the Combustion Process as a Result of Errors in the Thermodynamic Properties of Individual Substances," 435-438

Sections: G, H

Subjects: Isobaric combustion; Combustion products; Errors, combustion computations; Temperature

The thermodynamic description of many processes in closed systems is based on the assumption of the invariability of a certain state function during the process. For the case of isobaric combustion, this function is the enthalpy of the combustion products, equal to the enthalpy of the fuel. On the basis of this assumption, the partial derivatives of the parameters of the combustion process are obtained. Chosen as arguments are the heat of formation, the change in enthalpy, the statistical sum over molecular states, and the derivative of the statistical sum with respect to the temperature. Using reference data on the errors of the argument, an estimate is made of the errors in calculating the combustion temperature and the molecular weight of the combustion products.

Artyukh, L. Yu., Vulis, L. A., and Zakarin, E. A. "Numerical Study of a Laminar Gas Flame Jet," 322-329

Section: G

Subjects: Laminar flame; Gas flame jet

Results are presented of numerical integration in a computer of the chief problems of the theory of a flat, steady-state, straight gas flame jet, i.e., the combustion gases not premixed and of a homogeneous mixture (in a direct and an inverted flame jet). The computational results contain a detailed picture of the distribution of velocity, temperature, concentration of reagents, reaction rate, etc., for the case of a gas jet issuing from a nozzle of finite size into a wake flow.

Aslanov, S. K. and Kopeyka, P. I. "Contribution to the Problem of Constructing a Closed Theory of Spin Detonation," 487-490

Sections: I, G

Subject: Spin detonation theory

A theoretical model of spin detonation is constructed on the basis of the gas-dynamic relations in the scanning plane of the internal surface of the tube and on the basis of fulfillment of the fundamental theorem of conservation of kinetic moment. The model consists of the transverse front governing the detonation process and the wave configurations adjacent to the ends of this front. Taken into account are the sloping of the transverse wave with distance from the triple point and the influence of energy release in the Mach wave on the flow characteristics. The computational parameters of the core of spin detonation yield good agreement with the experimental data available in the literature.

Azatyan, V. V. and Aleksandrov, E. N. "Study of the Multiple Ignition of Carbon Monoxide Under Static Conditions," 646-649

Sections: B, H

Subjects: Ignitions, multiple; Carbon monoxide; Oxygen

A study is made of the multiple ignition of a mixture of CO and O_2 in a static setup in the 500-730°C temperature interval at pressures of 7-40 torr. The experiments were conducted in a vessel measuring 54 mm in diameter, coated with magnesium oxide and potassium tetraborate. The number of observed flare-ups during a single rapid immersion of the mixture into the vessel reached 40. It is shown that the characteristics of multiple ignition depend greatly on treatment of the surface by materials containing hydrogen.

Babaytsev, I. V., Kondrikov, B. N., Sidorov, T. T., and Tyshevich, V. F. "On the Detonability of Some Esters of Nitrous and Nitric Acids," 470-473

Section: G

Subjects: Detonability, structure relation; Nitrous acid esters; Nitric acid esters

The influence of the chemical structure of a material on its detonability is studied on the basis of some isomers from among a number of liquid esters of nitrous and nitric acids.

It was found that 2,3-butyleneglycoldinitrite in contrast to the 1,4- isomer, is not capable of detonating, despite the high rate of the primary decay reaction. The corresponding isomers of butyleneglycoldinitrate detonate at the same rate. But upon dilution with an inert liquid, detonation of the 2,3-isomer ceases at a diluent content smaller by half than that for the 1,4-isomer. Of the pair of isomers ethylnitratenitroethane, only the former has the capability of detonating. A complete analogy exists between the behavior of the substances under study during combustion and detonation. The observed differences in detonability are apparently due to the differing reactivity of the intermediate decay products, the composition of which is governed by the chemical structure of the substance.

Babenko, Yu. I. "Some Problems Frequently Encountered in the Theory of Nonstationary Combustion," 115-119

Section: G

Subject: Theory, nonstationary combustion

Problems for a linear parabolic equation with variable coefficients that are associated with a semi-infinite region are examined. An approach is proposed which permits finding the temperature gradient at the boundary of the region from a prescribed variation in boundary temperature (and vice versa) without solving the corresponding boundary-value problem. Examples are cited from the theory of nonstationary combustion.

Babich, A. P., Belyaev, N. M., and Ryadno, A. A. "Study of the Thermal Explosion of a Heterogeneous System of Two Semi-bounded Bodies." 49-52

Section: G

Subjects: Thermal explosion; Explosion, thermal, of heterogeneous systems

The boundary value problem of the thermal explosion of a heterogeneous system of two semi-bounded bodies is solved by the integral method.. An approximate analytical solution is obtained which permits determination of the phase interface temperature, the activation energy and the pre-exponential factor. The results of solution by the numerical and integral methods are compared.

Babkin, V. S. and V'yun, A. V. "Upper Limit of Flame Propagation with Respect to Pressure in a Bounded Volume," 289-292

Sections: E, G

Subjects: Flame propagation, upper limit; Pressure effect, on flame propagation

It is shown that free convection plays a considerable role in flame propagation limits. When a mixture is ignited in the center of a spherical vessel, the flame does not propagate through the whole volume at the limit, owing to convection and heat loss to the wall. An analogous phenomenon, partial flame propagation (upper pressure limit in a limited volume), is observed upon change in pressures if the rate of convection is commensurate with the visible flame velocity. The result of this phenomenon is that data from burning in pipes of varying diameter are inadequate. The conclusions of the paper emphasize the necessity of selecting a mixture explosion-hazard criterion.

Baev, V. K., Tret'yakov, P. K., and Yasakov, V. A. "Experimental Determination of the Combustion of Gas Air Mixtures in a Duct and of Diffusion Combustion in a Parallel Flow at High Velocities," 357-360

Section: G

Subjects: Combustion gas air mixtures; Duct combustion; Diffusion combustion

Given are the results of an experimental determination of the flame lengths in homogeneous mixtures in a plane duct with sudden expansion at duct inlet velocities of up to M = 1.25, namely, the separation length and the total flame length for combustion of an axisymmetric jet in a free coaxial, parallel flow of air and in a constant-cross-section duct in a Mach number range of 0.4 - 1.58. The results of measuring flame lengths by photometric methods and from the static pressure distribution are compared. The possibility of generalization of the geometric characteristics of the flame by a criterion is demonstrated.

Bakhrakh, S. M., Zubarev, V. N., and Shanin, A. A. "Shock Waves in Media with Phase Transitions," 553-560

Section: I

Subjects: Shock waves; Phase transitions

The motion of a medium which is a mixture of various phases of a substance is described by a system of equations of gas dynamics. Added to this system are relations determining the pressure at a given point in the medium via the density, specific internal energy, and mass concentrations of each of the phases; the equations of the phase state are assumed to be given; it is further assumed that the mixture is in a state of thermal and dynamic equilibrium, and the concentrations are determined from an equation of the conversion kinetics. The problem formulated in this manner is solved numerically by the method of resolution into physical processes. In each computational time step a calculation is made of the motion of the medium under the assumption of absence of phase transformations; then the variations in phase concentrations are calculated. Calculations were made which simulate graphite-diamond phase transformations behind the front of a shock wave generated by the impact of an aluminum plate on a graphite specimen. The computational results are compared with experiment.

Bakhtigozin, Sh. Kh., Naumov, M. S., and Shelukhin, G. G. "Calculation of a Turbulent Flame Jet at the Boundary of Parallel Flows," 347-351

Section: G

Subjects: Turbulent flame jet; Parallel flows

A method is proposed for calculating the gas-dynamic, temperature and concentration fields during the burning of a fuel and oxidizer in a system of plane, alternating parallel flows. It is assumed that the combustion takes place in the diffusion mode. In the initial section of the mixing zone, the solution is constructed as for the edge of a jet, while further on the calculation is performed approximately by the Pohlhausen-von Karman method. The relationship between the generalized longitudinal coordinate used in the equations and the physical longitudinal coordinate

is found experimentally. Also determined is the optimal regime of gradual supply of components over the length of the combustion chamber.

Baratov, A. N. "Ignition; Flame Propagation, Concentration Limits. Status of the Problem," 286-288

Sections: E, G

Subjects: Ignition limits; Flame propagation

It is noted that the existing ideas on the nature of ignition limits do not permit explanation of a number of phenomena and of the features inherent in these indicators. A standard method of determining ignition limits is analyzed, and it is pointed out that individual elements of the method are not as yet adequately founded. The important role of convection in the process of flame propagation at the limit is pointed out. Data on the combustion temperature at the lower and upper limits and on the influence of pressure on the ignition limits are examined. Directions for further study of the problem are indicated.

Barenblatt, G. I. "Methods of Combustion Theory in Polymer Mechanics," 15-23

Section: G

Subjects: Combustion theory; Polymer mechanics

Considered is the relationship between combustion theory and polymer mechanics. A survey is given of the studies in which the approaches and methods of combustion theory are applied to the problems of deformation, destruction and the flow of polymers. A number of typical examples is cited - those showing that the relationship between polymer mechanics and combustion process is based on what they have in common in a physical sense.

Barlas, R. A. "Burning of a Suspension at Low Concentrations of the Solid Phase," 171-174

Section: G

Subjects: Suspension burning; Solid phase burning

Steady-state combustion of a suspension is examined in the one-dimensional case. As a result of investigating the flame propagation mechanism, a method is suggested for calculating the velocity of the flame front and of the temperature field created during combustion. A method is proposed for determining the concentration limit of flame propagation as the minimum concentration at which the width of the reaction zone is not less than the mean distance between suspended particles.

Batalova, M. B., Bakhrakh, S. M., and Zubarev, V. N. "Calculation of Detonation Waves in Conical and Cylindrical Charges," 444-446

Section: G

Subject: Detonation waves

Numerical methods are used to solve two-dimensional problems of the degeneration of detonation in conical and cylindrical charges of diameter close to critical. The inducing pulse corresponded in amplitude and duration to the chemical reaction zone in a normal detonation wave. The problem reduces to the simultaneous solution of the equations of motion of the compressible medium, the equations of state and the kinetic equations, given in the simplest form. In calculating the motion of detonation waves in cylindrical charges it was found that the detonation wave can propagate in the incomplete energy-release region for some time. Upon further reduction of the diameter of the charge, complete degeneration of the detonation into a shock wave occurs. Calculations were made of detonation waves in conical charges at small cone angles (k). In this case, the detonation degenerates when the decreasing diameter becomes less than critical ($d_l < d_{crit}$). An approximate relation is given.

$$d_l = d_{crit}\ (1\text{-}bk)$$

where b is a weakly varying numerical coefficient.

With the aid of this relation the critical diameter of cylindrical charges is determined from the results of calculating the propagation of detonation waves in conical charges.

Bazhenova, T. V., Lobastov, Yu. S., and Kotlyarov, A. D. "Experimental Investigations of the Dissociation Rate of Water Vapor in Mixtures with Air," 658-661

Section: H

Subjects: Kinetics; Dissociations; Water - Air

An investigation is made of the rate constant of dissociation of water vapor mixed with air by measuring the time required for the equilibrium concentration of electrons to be reached at temperatures of 2500-4200°K in a shock tube. The time for equilibrium concentration of electrons to be reached coincided with the time required to establish a constant level of ir radiation after dissociation.

An estimate of the rate constant of dissociation of water mixed with air yielded a value of $1.10^{15} \exp(-\frac{9{,}100}{RT})$ in the 3500-4000°K temperature interval.

Belyaeva, M. S., Kitaygorodskiy, A. M., and Klimenko, G. K. "Physical Phenomena Occurring in the Initial Stages of Thermal Decomposition of Cyclotrimethylenetrinitramine," 785-788

Sections: I, H

Subjects: Cyclotrimethylenetrinitramine; Cottrell zones

The processes that occur in the initial stages of the thermal decomposition of

cyclotrimethylenetrinitramine are studied by special X-ray and electron microscope methods. The volume of the original molecule is calculated (180 Å^3) as is that of the reaction products (148 Å^3). Owing to the disparity in volume of the molecules of the original matrix and of the reaction products, stresses arise in the crystal which are sufficient for the generation and motion of dislocations. The conservative and nonconservative motion of the dislocations leads to polygonization of the crystal. The variables characterizing the small-angle edge are determined. The growth in imperfection of the crystal promotes the development of thermal decomposition in the volume. The accumulation of dislocations near the defects and the growth of Cottrell zones leads to cracking of the crystal and visible gas evolution begins.

Biryukov, A. S., Dronov, A. P., Kudryavtsev, E. M., Raynin, G. A., and Sobolev, N. N. "Study of a Gasdynamic CO_2 Laser," 694-697

Section: I

Subjects: Laser, CO_2; Gasdynamics; Carbon dioxide; Shock tube

A study is made of the influence of various factors on the gain in a gasdynamic CO_2 laser by means of a shock tube. Inversion in vibrational states $10^\circ 0$-$10^\circ 1$ in CO_2 is obtained in mixture of CO_2, N_2, He. It was found that nitrogen is not necessary for obtaining inversion sufficient for generation. The gain increases with increasing ratio [He]/[CO_2]. Addition of N_2 to the CO_2-He mixture leads to an increase in gain and to the presence of a maximum at constant partial CO_2 pressure and constant temperature before the slit. Also obtained is a temperature dependence of the gain for the mixture CO_2:N_2:He = 1.1:4:1 at constant CO_2 particle density. The measurements agree with the theoretical results.

Blinov, V. I., Lushpa, A. I., Khaylov, V. M., and Khudyakov, G. N. "Burning of Rich Kerosene Air Mixtures in a Tunnel Type Chamber," 416-420

Section : G

Subjects: Burning kerosene-air mixtures; Tunnel chamber burning; Kerosene-air mixtures

Discussed are the results of an experimental investigation of the influence of the air-fuel ratio (α = 1.0 - 0.3), the air temperature (T_{air} = 0 - 1000°C), and of the length of the combustion chamber (0.5 - 2.0m) on the degree of approximation of the composition and parameters of the combustion products to their equilibrium values in a chamber with an inner diameter of 100mm at a pressure of 1.1 atm. It was found that with decreasing α and T_{air} the difference between the experimental and theoretical parameters increases, while the curves of variation of the experimental data over the length of the chamber become shallower. It is shown that the process of achieving an equilibrium composition is limited by the heterogeneous burning of the solid carbon which has been generated upon the thermal decomposition of the kerosene in the initial combustion zone.

Bloshenko, V. N., Merzhanov, A. G., Peregudov, N. I., and Khaykin, B. I. "Theory of Gas Phase Ignition of a Drop," 227-233

Section: **B**

Subjects: Ignition, gas phase; Drop ignition

The gas-phase ignition of a drop of liquid fuel near critical conditions is examined with allowances for the inertia of the gas medium, and the correctness of replacing the equations of multi-component diffusion by the usually used equations of independent diffusion is analyzed. The problem was solved on a computer. It is shown that the inertia of the gas medium in problems of drop ignition cannot be disregarded, while at great distances from the limit, the ignition pattern is greatly dependent on the magnitude of the total pressure in the gas phase (or of the intensity of evaporation, which is defined as the intensity of evaporation in the absence of chemical reaction). It is shown that the multicomponent nature of the gas medium has a considerable effect on the ignition process.

Bobolev, V. K., Karpukhin, I. A., and Teselkin, V.A. "The Role of Chemical Interaction of Components upon Shock Excitation of an Explosion in Mixtures of Ammonium Perchlorate and Fuel," 515-518

Sections: **B, H**

Subjects: Shock excitation; Explosion; Ammonium perchlorate; Fuel; Ignition

The mechanism of shock excitation of an explosion of mixtures of ammonium perchlorate and fuel is examined on the basis of experimental data. An analogy is observed between the specific features of thermal decomposition of ammonium perchlorate under isothermal conditions and in the process of formation of local heating centers in ammonium-perchlorate/fuel mixtures in the case of shock. It is concluded that chemical interaction of the low-temperature oxidizer decomposition products with the fuel governs the process of excitation of an explosion.

Bondar, M. P., Staver, A. M., and Chagelishvili, E. Sh. "Study of the Influence of Solid Inclusions on the Change in Structure and Properties of Two-Phase Alloys Under Impact Loading," 549-553

Section: **I**

Subjects: Two-phase alloys; Impact loading; Shock loading

A study is made of the influence of shock waves on the change in structure and properties of two types of two-phase materials, namely: (1) soft Cu matrix with a small content of the solid phase of Al_2O_3 (0.97 - 4.6%); and (2) a solid base, WC (85-92%), and a soft binding component, Co. The plane impact loading pressure for (1) was 200 kbars, that for (2) 200 and 500 kbars, and 2 Mbars for compression of alloys of the second type in cylindrical ampoules. Under these conditions, the relative consolidation of alloys of the first type decrease with increasing volumetric

fraction of deposits; the degree of consolidation depends on the shape of the deposits; the consolidation greater for alloys with deposits of nearly spherical shape; the consolidation is preserved after annealing at 800°C. A high degree of consolidation was obtained for alloys of the second type, where the solid phase is consolidated. The principal factor contributing to consolidation of alloys of both types 1 and 2 is the high density of the dislocations that exist after explosive loading.

Dremin, A. N., Kanel, G. I., and Koldunov, S. A. "Study of Spall in Water, Ethyl Alcohol and Plexiglass," 569-579

Section: I

Subjects: Water; Alcohol; Plexiglass; Lucite; Perspex; Spall

A new modification of the spall method is proposed for investigating the strength characteristics of liquids and other low-strength substances subjected to tensile forces for a period of $\sim 10^{-7}$ to 10^{-6} sec. In the proposed method the pressure or mass-velocity profiles in the shock wave are recorded, as are the pressure or mass velocity impulses generated when the spall plate impacts on the plexiglass target. The thickness of the spall plate and the critical rupture stress are determined from the experimental results. Strength values are obtained for distilled water, ethyl alcohol, rectified spirit and plexiglass. It is found that spall in liquids is not friable. A spall mechanism based on a bubble model of the strength of liquids is discussed.

Drukovanyy, M. F., Kormin, V. M., and Oberemok, O. N. "Detonation Mechanism of Water Filled Granulated Explosives," 459-463

Section: G

Subjects: Detonation mechanisms; Granulated explosives, water filled

Given and analyzed in this paper are the results of experiments with water-filled granulotol and grain-granulite of "hot" mixture. On the basis of a study of the detonation rate under various explosion conditions, distance and nature of transmission of the detonation, sensitivity, critical and limit detonation diameters, nature of the excitation of detonation, mass velocity of the material in the detonation wave, chemical reaction zone width and time, it is shown that initiation of reaction in water-filled compounds takes place with compression of the material by a powerful shock wave passing through the granule. A consequence of this detonation mechanism is a sharp increase in destruction volume when water-filled explosives (relatively dry) explode in charges of small diameter, as confirmed by open-air and underground explosions.

D'yachenko, N. Kh. and Sviridov, Yu. B. "Combustion Problems in Diesels," 254-264

Section: G

Subjects: Combustion, diesels; Diesel combustion

The chief problems of combustion theory for a charge inhomogeneous in concentration and temperature, something characteristic of diesels, are formulated. They break down into the problems of mixture formation, ignition, and combustion. The mixture-formation problems, which include the three aspects of the liquid structure of the unsteady jet of atomized fuel, the heating and evaporation of the fuel, and the mixture-formation dynamics, reduce to determining the concentration and temperature fields. The mixture-formation theory that is developed permitted finding, from experimental data, the real values of the temperature and of the composition of the mixture in the fuel jet and their dependence on the initial conditions. Ignition problems in a diesel reduce to interpreting the oxidation kinetics and the phenomenology of flame formation in the charge with allowance for the true values of the temperatures and concentrations. The experiments showed that in an inhomogeneous charge, the cold flame goes directly into the fuel, the inhomogeneous charge ignites faster than a homogeneous one. The problems of combustion in a diesel are connected with deciphering the mechanism of flame propagation in an inhomogeneous series. The experiments showed that the most varied cases of combustion are possible in a diesel, from flame propagation in a homogeneous medium to diffusion burning.

Elyutin, V. P., Mitin, B. S., and Samoteykin, V. V. "Influence of High Temperature Oxidation on the Particular Features of Ignition of a Finely Dispersed Aluminum Powder," 241-244

Section: **B**

Subjects: Oxidation, high temperature; Ignition, aluminum powder; Aluminum powder ignition

On the basis of the referenced experimental investigations of the oxidation of aluminum in the 450-1700° C range, it is proposed to describe the rate of oxidation of finely dispersed particles during the induction period by means of the expression

$$K = K_1 \exp\left(-E/RT - \int_0^t \frac{dt'}{\tau_1} \right) + K_2 \left[1 - \exp\left(- \int_0^t \frac{dt'}{\tau_1} \right) \right] \exp\left(-E_2/RT - \int_0^t \frac{dt'}{\tau_2} \right)$$

where E, E_2, τ_1, τ_2, K_1 and K_2 are experimentally determined quantities.

This expression is used to calculate the limit conditions of ignition of aluminum as a function of particle size. The computational results are compared with the data of other authors.

Emanuel, N. M. "The Mechanism of Liquid Phase Oxidation," 608-624

Section: **H**

Subjects: Liquid phase oxidation; Chain reactions; Catalysis

This paper is a survey of contemporary studies of the mechanism and kinetics of oxidation reactions in the liquid phase. Slow oxidation chain reactions are studied, including the mechanism of radical initiation of reaction and its effect on the formal kinetics of chain oxidation, reaction in multi-component systems, coupled chain reactions, homogeneous catalysis, inhibited oxidation, and a number of other topics.

Ezhovskiy, G. K., Mochalova, A. S., and Ozerov, E. S. "Ignition and Combustion of a Magnesium Particle," 234-240

Sections: B, D, G

Subjects: Ignition, particle; Combustion, particle; Magnesium particles

Outlined in the article are the results and methods of an experimental study of the characteristics of ignition and combustion of single suspended and volatile particles of magnesium. On the basis of experimental data, a calculation is made of the kinetic constants of heterogeneous oxidation reaction of magnesium in water vapor and oxygen. Using the constants obtained in the calculations, the dependence of the limit ignition temperature and the induction time of the magnesium particle is calculated as a function of various parameters of the medium. A semi-empirical formula is presented for the dependence of the combustion rate constant of the magnesium particle on the concentration of oxidizer in the medium and on the pressure of the medium.

Fedotov, N. G., Sarkisov, O. M., and Vedeneev, V. I. "Determining the Probabilities of Heterogeneous and Homogeneous Deactivation of Deuterium Molecules," 654-657

Sections: H, B

Subjects: Kinetics; Fluroine; Deuterium; Vibrational deactivation

The upper self-ignition limit of the reaction of fluorine with deuterium is studied. The probabilities of heterogeneous deactivation of vibrationally excited deuterium molecules on a molybdenum glass surface treated by the reaction of fluorine with deuterium in the 77-275° K temperature interval are determined. The rate constants of homogeneous deactivation of D_2 (v=1) on deuterium molecules are determined at temperatures of 241-275° K.

Filippov, A. V. "Mechanism of Flame Propagation in a Forest Fire," 157-160

Section: D

Subjects: Flame propagation; Forest fire

This work was conducted for the purpose of clarifying the principal stages of the process and of generalizing the influence of the basic variables on the flame propa-

gation rate in a forest fire. The experiments were performed both with an experimental set-up and in the field. As a result, it was found that the flame propagation mechanism is influenced in specific ranges of values by the following: the moisture content of the burning matter, the speed and direction of the wind, and the rate of pyrolysis of the combustible material.

Fogel'zang, A. E., Adzhemyan, V. Ya., and Svetlov, B. S. "Role of the Reactivity of an Oxidizing Group During the Combustion of Explosive Compounds," 63-66

Section: I

Subjects: Explosive compound combustion; Oxidizing group reactivity

Studied in a constant-pressure bomb at 1-400 atm was the combustion of permanganate, bromate, chlorate, perchlorate, nitrite, periodate, iodate, bi-trichromate of ammonium, as well as periodates, iodates, perchlorates and nitrates of methylamine, guanidine and benzylamine. Correlation was found between the combustion rate and the magnitude of the oxidation potential characterizing the relative reactivities of the oxidizers appearing in the molecule of the explosive compound. It is suggested that on the basis of the relative potential it is possible to predict the relative normal combustion rates of substances with various oxidizers and the same fuels.

Fortov, V. E. "Construction of the Equation of State of Condensed Media by a Dynamic Experiment," 561-564

Section: I

Subjects: Equation of state; Condensed media; Nickel

Considered is a universal method of constructing the equation of state of condensed media from a shock-wave experiment without drawing on theoretical ideas as to the properties and nature of the medium being investigated. The method is based on the use of the second theorem of thermodynamics and on experimental data relating to impact compression of continuous and porous material specimens. The equation of state of nickel is constructed as an example.

Frolov, Yu. V., Korotkov, A. I., and Dubovitskiy, V. "Combustion of Mixed Homogenized Systems," 67-69

Section: G

Subject: Combustion, mixed homogenized systems

Briefly examined in the article is the combustion scheme of mixed condensed systems with readily decomposing components as a function of the degree of dispersion of the latter.

Given are the results of study of the combustion process of extremely fine-grained systems ($< 2\ \mu$). It is shown that the introduction of catalysts or finely-dispersed aluminum into such a "homogenized" mixture increases the combustion rate to 70-100 mm/sec at a pressure of 100 atm.

Gavrilin, A. I., Mel'nikov, M. A., and Shneyder, V. B. "Ignition of Initiating Explosives by an Electrical Spark," 44-48

Section: B

Subjects: Ignition of explosives; Electrical spark ignition; Explosives, ignition of, by electrical sparks

Considered in this report, within the framework of thermal ignition theory, is the process of activation of detonation of initiating explosives by an electrical spark.

The model defines the processes which take place on the effective surface of the source and permits calculation of a number of ignition characteristics. A comparison of the theoretical and experimental data shows satisfactory agreement of the results. This fact allows the conclusion that the initiation of inorganic azides by an electrical spark is of a thermal nature.

Gaynutdinov, R. Sh., Enaleev, R. Sh., and Averko-Antonovich, V. I. "Investigation of the Linear Pyrolysis of Material Subjected to a Powerful Stream of Radiant Energy," 120-123

Sections: I, G

Subjects: Linear pyrolysis; Radiant energy

An experimental method of investigating the linear pyrolysis of materials is presented and the formal-kinetics parameters for polymethylmethacrylate and a cellulose material are determined. The results obtained for PMM are compared with the data of other authors and their satisfactory agreement is shown. The dependence of the total heat of gasification on the linear pyrolysis rate is obtained. It is found that the heat of gasification increases with increasing linear pyrolysis rate both for PMM and the cellulose material.

Gel'fand, B. E., Gubin, S. A., Kogarko, S. M., and Mironov, V. N. "Dynamics of Ignition of a Gas Liquid Fuel Mixture Behind the Front of a Weak Shock Wave," 494-497

Section: B

Subjects: Ignition; Shock waves; Gas liquid fuel mixture

Studied in this paper is the ignition of kerosene drops in oxidizers of composition $0.3\ O_2 + 0.7\ He$, $0.3\ O_2 + 0.7\ Ar$, $0.3\ O_2 + 0.7\ N_2$, and $0.3\ O_2 + 0.7\ CO_2$ by a heated gas source with a temperature of from 1000 to 1800°K. It was found that with $T > 1700°K$ the ignition delay is governed by the breakdown time of the drops, and

at $1200 < T < 1700°K$ by the sum of the breakdown time and the induction time of thermal self-ignition of a mixture of oxidizer and microdrops formed when the initial particles are destroyed.

Genich, A. P., Levin, V. A., and Osinkin, S. F. "Oxidation of Ammonia in Air Behind a Direct Compression Shock," 662-667

Section: H

Subjects: Kinetics; Ammonia; Oxygen; Shock compression

The ignition delay time is determined for various mixtures of ammonia and air. The best known kinetic schemes of the oxidation process are investigated. The analytic solutions permit critical evaluations of possible variants and some preference to be given to the scheme proposed by Miyama and Takiyama.

Genkin, K. I. and Khazanov, Z. S. "Study of the Mechanism of Combustion in an Engine," 409-415

Section: G

Subject: Engine combustion

Data are obtained on propagation rates, width and structure of the combustion zone during spark and precombustion-chamber flame jet ignition of methane-hydrogen-air mixtures by synchronous indication and schlieren moving-picture recording. The influence of the composition of the mixture and of the normal combustion rate on the combustion process is investigated.

Gilinskiy, S. M. and Zak, L. I. "Hypersonic Unsteady Flow of a Burning Gas Mixture Past Bodies of Differing Shape," 374-381

Section: G

Subjects: Burning gas mixture; Hypersonic unsteady flow

A study is made of unsteady burning modes arising during hypersonic flow past a wedge and a blunt body. A solution for a thin wedge executing small oscillations about the edge as a pivot was obtained analytically in a linear approximation. It is shown that small oscillations of the wedge bring about analogous oscillations, phase-shifted, of the shock wave. The "series truncation" method is used; the solution is sought in the first approximation. The two-dimensional equations were integrated by the finite-difference method using characteristic relations for the boundary points. The development with time of perturbations introduced into the initial and boundary conditions is investigated. Found was a range of stable values of the governing parameters that turned out to be considerably broader than for one-dimensional flows upstream of a piston. Self-oscillations of the gas were detected, and an explanation is given of the mechanism of origination of annular waves and of the formation of the periodic wave structure of the combustion front.

Glazkova, A. P. and Andreev, O. K. "Influence of the Nature of Fuel and Catalyst on the Combustion of Mixtures Based on Ammonium and Potassium Perchlorate," 78-82

Section: I

Subjects: Combustion of perchlorate mixtures; Perchlorate fuels; Catalyst in perchlorate combustion

The combustion of model mixtures (stoichiometric) was studied in a constant pressure bomb in a pressure range of up to 1,000 atm. Used as the fuel were substances yielding ammonia (ammonium chloride) upon decomposition, with a small hydrogen (ammonium oxalate) content, hydrocarbons and pure carbon. It is shown that the fuels containing ammonium oxidize most difficultly during combustion; the lower pressure limit of combustion for them is 700-800 atm, the combustion rate near the limit being $\sim 1 g/cm^{2x}$sec. The addition of catalysts leads to a sharp drop in the pressure limit (hundreds of atmospheres) and to an increase in the combustion rate by a factor of tens. Mixtures with potassium perchlorate burn faster for the same fuel; the opposite pattern prevails for catalyzed mixture, in that those with an ammonium perchlorate base burn faster. From an analysis of the results it is concluded that catalysts increase the proportion of reactions occurring in the condensed phase.

Goncharov, E. P., Merzhanov, A. G., and Shteynberg, A. S. "Thermal Decomposition of Condensed Systems at Elevated Temperatures," 765-770

Section: H

Subjects: Thermal decomposition; Thermogravimetry; Ammonium perchlorate; Polystyrene

Thermographic and thermogravimetric methods are devised for the study of the kinetics of thermal decomposition of condensed systems. The kinetics of decomposition of ammonium perchlorate, polystyrene and mixtures of them at temperatures of 250-450°C is studied. A kinetic equation is obtained for the high-temperature decomposition of ammonium perchlorate in the form

$$\frac{d\eta}{dt} = 2.2 \cdot 10^9 \exp(-16{,}000/RT)\,(1-\eta - z\,0.02\sqrt{z}),$$

where η is the depth of conversion, T is the temperature and z is the root of the transcendental equation $\sqrt{z} = 0.005\, ln\,(1-\eta-z) + 0.93$.

Some effects of the high-temperature interaction of ammonium perchlorate with polymers are described.

Gorbunov, G. M. and Khristoforov, I. L. "Mechanism of the Burning Process Behind Front End Assemblies and in the Zone of Inflow of the Secondary Air in the Chambers of Gas Turbine Engines," 421-425

Section: G

Subjects: Gas turbine engines

This report is devoted to an experimental study of the burning process in the initial section of flame tubes behind a front end assembly and in jets of secondary air. Presented are the principal results obtained behind two typical front end assemblies in serial chambers, differing by the method of introducing the primary air into the fire tube. Two combustion schemes were established:

1. a heterogeneous fuel-air mixture is supplied to the combustion zone, and the combustion products are drawn from the combustion zone;
2. the fuel and air diffuse to the combustion zone from two different sides, and the combustion products are drawn out of both sides. In studying combustion in jets of secondary air it was found that if the combustion takes place behind the front assembly of the flame tube by scheme 1 or 2, the same kind of scheme is realized during the burning of fuel around a jet of secondary air in the first belt of orifices.

Gostintsev, Yu. A., Sukhanov, L. A., and Pokhil, P. F. "Nonstationary Processes During the Combustion of Powder," 87-93

Section: G

Subject: Combustion of powder

On the basis of the phenomenological theory of nonstationary powder combustion an examination is made of the interaction of pressure waves with burning powder and the possible types of perturbations generated by the powder combustion zone under nonstationary conditions; the constant component of the combustion velocity is calculated for sinusoidal change of one of the parameters governing combustion; a more complete system of equations is formulated, describing nonstationary processes in a semi-closed volume; and the stability of processes inside the chamber is investigated.

Gremyachkin, V. M. and Istratov, A. G. "Stability of a Plane Flame in a Stream with a Velocity Gradient," 305-308

Section: G

Subjects: Plane flame stability; Velocity gradient

Considered is the problem of a plane flame front under conditions when the flow velocity component tangent to the front grows linearly along the front, taking into account the difference between the diffusion coefficient D and the thermal diffusivity η. The stability of the steady-state reactions to curvature of the front is investigated. It is shown that for $D < \eta$ flame extinction is possible when the gradient of the tangent velocity of the flow increases, and when $D > \eta$ the front may be unstable to curvature.

Grigor'ev, Yu. M. "Evaporation and Ignition of a Drop of n-Pentane in an Oxidizer Medium," 221-226

Section: B

Subjects: Evaporation; Ignition; n-Pentane

The thermogravimetric method is applied to the experimental study of the characteristics of evaporation and ignition of a drop of n-pentane in an atmosphere of air, oxygen and nitrogen in a broad temperature interval. The appreciable influence of gas-phase oxidation reactions on the evaporation processes is demonstrated. The ignition characteristics are determined as a function of the parameters of the process. The macrokinetic characteristics of the reactions taking place during ignition of a drop are calculated using data on ignition limits.

Grishin, A. M. and Kuzin, A. Ya. "Heterogeneous Homogeneous Combustion of a Reacting Plate in a Stream of Oxidizer," 38-43

Section: G

Subjects: Heterogeneous combustion; Homogeneous combustion; Combustion, in an oxidizer stream

Given is a general mathematical model of the heterogeneous-homogeneous inflammation of a reacting plate by a stream containing an oxidizing component. In the particular case of a plate in a frozen stream approximate analytical formulas are obtained for the induction period and the ignition limit by means of two approximate methods, which were verified by comparison with data obtained by numerical solution of the problem on a BESM-4 computer.

It was found that two modes of heterogeneous combustion exist, namely, self-inflammation and ignition.

In the first case the induction period increases with increasing velocity of the "cold" gas stream and in the second it decreases with increasing velocity of the "hot" stream.

It was established that injection as a result of thermal destruction of the surface increases the induction time if homogeneous reactions are absent, and the mixture cannot be considered as an effective binary mixture if the molecular weight of the components are greatly different.

Gurevich, M. A., Ozerova, G. E., and Stepanov, A. M. "Calculation of the Combustion Rate of a Metal Particle Taking Oxide Condensation into Account" 175-181

Section: G

Subjects: Combustion rate; Metal particle; Oxide condensation

The rate of vapor-phase combustion of a stationary metal particle is calculated. Diffusion combustion is assumed. At any point (including the surface of the par-

ticle and the combustion surface), the partial pressure of the oxide vapor is taken to be equal to the pressure of the saturated vapor at the temperature that is established at the given point. It is shown that in the presence of oxide condensation in the space surrounding the particle not only bulk heat sources are unavoidable, but also discharges of material. It was assumed that the condensed oxide accumulates on a surface whose radius is determined from the condition of the mass velocity of the gas equalling zero on it. The calculated combustion rate constants of a magnesium particle are compared with the experimental data of other authors.

Gurevich, M. A., Ozerova, G. E., and Stepanov, A. M. "Calculation of the Flame Propagation Rate in a Gas Suspension of Particles of a Solid Combustible," 199-203

Section: D

Subjects: Flame propagation; Solid combustible; Gas suspension of particles

An examination is made of the problem of propagation of a plane flame front in a one-dimensional flow of a suspension of particles of a solid combustible in a gas containing an oxidizer. It is assumed that heat-up of the cold mixture by the release of heat from the reaction is accomplished only by the molecular thermal conductivity of the gas. The rate of flame propagation is taken to be the mixing rate of the original gas suspension at which stationary longitudinal reactant temperature and concentration fields become possible. Numerical methods are used to calculate the dependence of the flame propagation rate on the initial parameters.

Gusachenko, L. K. "Possibility of Oscillations of Very Low Frequency in a Semi-Closed Volume," 100-103

Sections: G, H

Subjects: Oscillations in solid propellant combustion; Solid propellant combustion

Considered is the operation of a chamber with a supersonic exhaust of products of a main charge [of solid propellant] with a fast-burning rod inserted, without a gap, along its axis. It was found that oscillations associated with deformation of the conical shape of the combustion surface are possible.

The stability condition

$$-3.603 < 2(\nu_2 - \nu)/(1 - \nu) < 2,$$

$$\nu = \frac{d \ln u}{d \ln p}, \quad \nu_1 = \frac{d \ln u_1}{d \ln p},$$

where u and u_1 are the burning rates of the propellant and rod, was obtained by the method of small perturbations and was confirmed by the numerical calculations of the nonlinear problem.

Gussak, L. A. "Precombustion Chamber Flame Jet Initiation of Avalanche Activation of Combustion," 401-408

Sections: H, G

Subjects: Precombustion chamber; Flame jet initiation; Avalanche combustion activation

An attempt is made to explain the method of precombustion chamber flame jet initiation by the process of avalanche activation of combustion of various fuel mixtures on the basis of the mechanism of continuously branched chain chemical reaction. The method eliminates almost completely autocatalytic, slow, incomplete, and unstable development of chemical reactions and excludes the possibility of degenerate chain branching. This leads to considerable abbreviation of the delay period and to decrease of the ignition temperature, to an increase in the rate, to enhancing the completeness and expanding the limits of effective combustion with respect to temperature, pressure, composition, and flow rate of the working mixture.

Gussak, L. A., Samoylov, I. B., Semenov, E. S., Murashov, A. F., Ozerov, E. A., and Stotland, A. I. "The Terminating Stage of Turbulent Burning of a Heterogeneous Mixture," 365-369

Section: G

Subjects: Turbulent burning; Burning, terminating stage; Heterogeneous mixtures

Investigated is subsonic gas flow in the nozzle zone of a model combustion chamber of a gas-turbine engine at temperatures of 700-1000°C. It is shown that the gas flow is not an equilibrium flow, and, consequently, the thermodynamic approach to determine the properties of such a flow may prove to be inadequate. The study was made with an experimental combustion chamber in which diesel fuel was ignited. The nonequilibrium state of the combustion products was established on the basis of data on the ionization of gases and on the spectra of their luminescence. Thermocouples measured the average temperature and, simultaneously, the composition of the gas-flow combustion products was determined. The data obtained permit concluding that slow volumetric reactions of full burning of the hydrocarbons occur at regimes of 700 and 800°C in the flow. The much greater nonuniformity observed at the 900 and 1000°C regimes is due chiefly to entrainment of flame centers from the primary zone of the combustion chamber and, in part, to burn-up reactions in the volume. An attempt is made at getting an experimental foundation for the possible mechanism that leads to the appearance of centers with a slow bulk reaction.

Itin, V. I., Nayborodenko, Yu. S., Kozlov, Yu. I., and Ushakov, V. P. "Gasless Combustion of a Mixture of Metallic Powders," 142-147

Section: G

Subjects: Gasless combustion; Metallic powders

The paper is devoted to the gasless burning of powder mixtures of nickel-aluminum and copper-aluminum, to the kinetics of reaction diffusion in these mixtures and of the process of increase in briquette volume owing to the formation of new gases. Equations are obtained describing thermal and volumetric effects in metal-powder mixtures.

Ivanov, B. A., Izmaylov, E. M., Narkuskiy, S. E., Nikonov, A. P., and Pleshakov, V. F. "Limit Conditions of Propagation of Combustion through Metal Specimens in Gaseous Oxygen," 148-152

Section: G

Subjects: Metal combustion; Propagation rate; Oxygen limit in metal combustion

Calculations are made of combustion propagation rates and of the minimum oxygen presures at which the propagation of combustion takes place for cylindrical specimens of Kh18N9T and 3Kh13 steel, copper iron and low-carbon steel. The flow rate of the oxygen was varied from 0 to 100m/sec, the specimen diameter from 1.2 to 6.0 mm. The experimental data are in good agreement with a model in which burning on the surface of a liquid drop of metal is controlled by the diffusion of oxygen through the gas; they support the hypothesis of independence of the limit (minimum) thermal flux density necessary to sustain combustion on the pressure, specimen diameter, and flow rate of the gas.

Kalabukhov, G. V., Ryzhik, A. B., Yusmanov, Yu. A., Sidorov, V. M., Osipov, B. R., and Faerman, S. N. "Influence of the Reaction Kinetics Properties of an Igniting Flow on the Burning of Aluminum Powders," 204-206

Sections: H, B

Subjects: Aluminum powder combustion; Reaction kinetics of igniting flow

A shock tube is used to study the combustion of aluminum powder as it is affected by detonation waves of varying intensity and chemical composition. It is found that increasing the detonation rate of gaseous mixtures inhibits combustion to a degree commensurate with the rate of decrease of the detonation temperature. The influence of oxygen, carbon dioxide, and small quantities of nitrogen and argon on the process of burning of disperse aluminum is positive. Light gas (hydrogen, helium) dilution of the stoichiometric mixture of hydrogen with oxygen leads to a decrease in the degree of powder combustion.

Kalinin, A. P., Leonas, V. B., and Sermyagin, A. V. "Kinetic Properties of Gases at High Temperatures: Determination of Collision Integrals," 679-689

Section: I

Subjects: Molecular beams; Scattering; Kinetic theory

The values of the reduced collision integrals $\bar{\Omega}^{(1,1)}$, $\bar{\Omega}^{(2,2)}$ are calculated in the 1000-10,000°K temperature interval for 24 systems that are components of the terrestrial atmosphere and of the planets. A calculation is made of $\bar{\Omega}^{(1,s)}$ from the averaged anisotropic interaction potentials obtained from data on the scattering of fast molecular beams. To take the nonsphericity into account, a noncentral field model was chosen in the form of the sum of the contributions of force centers which are placed at points where atoms of the interacting molecules are located and which are assumed to be identical.

Kapralova, G. A., Margolina, E. M., and Chaykin, A. M. "Rate Constants of Some Elementary Stages of Fluorine Hydrogen Reactions," 634-637

Section: H

Subjects: Rate constants; Fluorine-hydrogen; Kinetics

Measured are the rate constants of elementary stages of the reaction of fluorine with hydrogen, which take place with the participation of vibrationally excited molecules. The rate constants of the branching reaction

$$H_2^* + F_2 \xrightarrow{k_3} H' + HF + F'$$

and of the process of vibrational-translational deactivation of H_2 upon collision with helium, determined at room temperature, turned out to be $\sim 2 \times 10^{-20}$ cm^3/sec and $\sim 10^{-17}$ cm^3/sec, respectively. The constants of the process of vibrational-translational deactivation of H_2 on Ar, H_2, N_2, CF_4, and He do not differ from each other by a factor greater than two. The branching rate constant in the 300-400°K temperature interval has the form

$$k_3 = 2.10^{-17} e^{-4500/RT} \text{ cm}^3/\text{sec}.$$

The rate constant of the process of transfer of a vibrational quantum from HF* to H_2 at 300°K is $\sim 8.10^{-14}$cm^3/sec.

Karachevtsev, G. V. and Tal'roze, V. L. "Ionic Pressure in a Flame," 729-736

Sections: I, H

Subjects: Ionic pressure; Flames; Chemilonization; Ion molecule reactions

A survey is given of the experimental methods of studying electron-ionic processes in a flame. The elementary processes of electron-impact ionization, of chemical ionization and of ionization upon heavy-particle collision are discussed. The ion-molecular reactions taking place in flames are sited, as are the processes of attachment of electrons with the formation of negative ions and charged-particle recombination processes. Ion-electron processes in some specific flame types with non-equilibrium and equilibrium ionization are examined.

Karpinskiy, B. V., Ryabikin, Yu. A., Mansurov, Z. A., Dubinin, V. V., Gershenzon, Yu. M., and Ksandopulo, G. I. "Mechanisms of the Effect of Synergism in the Combustion of Hydrogen with Additions of Diethylamine and Tetrafluorodibromoethane," 716-720

Sections: E, H

Subjects: Inhibition; Propagation limits; Hydrogen; Diethylamine; Tetrafluorodibromoethane

The synergism effect was detected in the inhibition of the flame propagation limits of hydrogen with air by adding diethylamine (DEA) and tetrafluorodibromoethane (TFDBE). The propagation limits are narrower when the inhibitors, in various quantities, are introduced simultaneously than when they are introduced separately. Required for complete suppression of ignition is 18% TFDBE or 12% DEA. The introduction of 3.5% DEA and 3.5% TFDBE is just as effective. Superequilibrium concentrations of hydrogen atoms were detected by the EPR method in a hot flame of hydrogen with air. Weakly pronounced synergism is also observed when the concentration of hydrogen atoms is dependent on addition of the inhibitor. The possible synergism mechanisms are discussed.

Karpov, V. P. "Reaction of a Flame Front to the Influence of a Shock Wave," 382-385

Section: G

Subjects: Flame front; Shock wave

An experimental examination is made under shock-tube conditions of the interaction of a shock wave with flames of methane-oxygen mixtures at an initial pressure of 200-350 mm Hg while recording the process with a high-speed SFR motion-picture camera by the Toepler method. By comparison with the process of interaction of a wave with a flame for the spherical case, the sharp acceleration of the combustion with generation of shock waves of considerable amplitude is discussed on the basis of loss of stability of the interface of media of differing density upon pulsed acceleration.

Kleymenov, V. V., Mal'tsev, V. M., Seleznev, V. A., and Pokhil, P. F. "Aspects of the Thermodynamic Equilibrium of Combustion Products During Discharge," 426-429

Sections: I, G

Subjects: Combustion product discharge; Thermodynamic equilibrium, combustion products

Considered is the establishment of equilibrium of the combustion products of H powder and of H powder with 5% aluminum behind the nozzle of a model rocket engine in the zone before the shock. By means of photographic and spectral

methods, a study is made of the spectrum of the discharge products in the 0.3 - 1.3 μ range, and the absorption capacity and the translational and electronic temperatures of the combustion products are estimated at distances of 0.2 and 3.0 cm from the exit-plane of an "eye" type of nozzle. It is shown that the absorptivity of the combustion products is low, increases with decreasing wavelength, and decreases with distance from the nozzle and increase in pressure in the combustion chamber. The difference between the experimentally measured translational temperature of the combustion products and the electronic temperatures of the detected intermediate combustion products indicates the absence of complete thermodynamic equilibrium of the combustion products. The conclusion is drawn that radiation of the combustion products is in partial equilibrium, that is, an equilibrium energy distribution is achieved only for a translational degree of freedom and a certain effective translational temperature of the jet of combustion products as a whole corresponds to this degree of freedom.

Klimenko, G. K. and Frolov, E. I. "Particular Features of the Initial Stages of Low Temperature Decomposition of Ammonium Perchlorate," 745-747

Section: H

Subjects: Ammonium perchlorate; Kinetic mechanisms

The low-temperature isothermal thermolysis of ammonium perchlorate in the 160-220°C temperature range is examined. An analysis is made of chlorine-containing decomposition products in the condensed phase in the early stages of the process. It is demonstrated that the main chlorine-containing products of thermolysis are $HC10_4$, $C1_2$, and HC1. No appreciable accumulation of $HC10_4$ occurs in the induction period. The perchloric acid forms simultaneously with the remaining products of thermolysis. An analysis of the results shows that the $HC10_4$ and the other products of thermolysis are formed in the early stages as a result of parallel processes. In the initial stages of the process ($\eta < 0.01$), from 50 to 90% of the products of thermolysis are in the condensed phase. A scheme for the decomposition of the ammonium perchlorate is proposed.

Klimov, A. M. "Theory of an Arbitrary Flame Front," 299-304

Section: G

Subject: Flame front theory

In order to expand the possibilities of an approach to a description of combustion of mixed gases in terms of laminar flame fronts, it is necessary to study flames of complex shape in an inhomogeneous hydrodynamic field. The aim of this paper is to analyze the structure of an arbitrary flame front. The main attention is devoted to spark flames. Also discussed are the reasons for the inaccuracy of the "flame elongation concept".

Klochkov, I. S. "Excitation of an Explosion When a Metal Surface Rubs Against an Explosive," 519-522

Section: B

Subjects: Explosion; Ignition; Detonation; Frictional ignition; Metal-explosive

The occurrence of an explosion when a metal surface rubs against an explosive containing solid particles is examined. It is hypothesized that the reason for the explosion are the metal particles stripped from the surface when a solid particle scratches it. Found for this case is the critical pressure of sliding contact with the explosive at which explosion must occur; the dependence of this pressure on the properties of the explosive, the metal, and the particle size is also established. It is shown that the explosion occurs accidentally. A relationship is found between the probability of occurrence of an explosion and the critical pressure and parameters characterizing the friction zone.

Klyauzov, A. K., Arsh, M. M., Madyakin, F. P., and Filaretova, G. A. "Ignition of Metal Powders in the Combustion Products of a Model Fuel," 250-253

Section: B

Subjects: Ignition, metal powders; Metal powder ignition; Combustion products

A method is described for determining the ignition delay time of a system of metal particles in the combustion products of a model fuel. It is shown that the ignition delay time of the metal particles depends on the nature and degree of dispersion of the metal, the presence of various inorganic impurities, the combustion temperature, and the composition of the combustion products of the model fuel. The principal oxidizing agent in the flame for aluminum particles at a model-fuel combustion temperature above 2,300°K is H_2O.

Knorre, V. G. and Mamina, N. K. "Investigation of the High-Temperature Interaction of Carbon with Oxygen in a Shock Tube," 668-671

Section: H

Subjects: Kinetics; Oxygen; Shock tube; Carbon

Studies are made of the interaction of carbon with oxygen in a shock tube in the 1850-2450°K temperature interval and at a partial oxygen pressure behind the reflected shock of 0.6 - 0.8 atm. Carbon black with a mean particle diameter of 450 and 1500Å was used as the object of the investigation. The reaction rate was measured optically from the change in absorption of a signal from a standard source by suspended carbon. At temperatures up to 2000°K the interaction rates are close to the rates obtained under comparable conditions by Strickland and Constable. In contrast with their data, however, a rate maximum was not detected at temperatures above 2000°K.

Kochubey, V. F., Moin, F. B., and Shchemelev, G. V. "Study of the Kinetics of Combustion of Mixtures of H_2 and CO," 642-645

Section: H

Subjects: Kinetics; Hydrogen; Carbon monoxide; Oxygen; Combustion

A study is made of the kinetics of reactions taking place during the combustion of mixtures of hydrogen and carbon monoxide at pressures of 80-850 mm Hg in the 510-1,100° C temperature range. The experiments were carried out in a continuous reactor under isothermal conditions. The only reaction products, aside from unreacted CO and H_2, are CO_2 and H_2O, which were measured quantitatively. At low degrees of conversion of CO and H_2, the ratio $A = [CO_2][H_2]/[H_2O][CO]$ at $T > 800°C$ does not depend on either the pressure or the composition of the mixture.

It was found, for the first time, that at $T < 800°C$ the value of A increases with increasing pressure and at high pressures depends also on the composition of the mixture. A reaction mechanism is suggested which explains the experimental data obtained.

Kondrat'ev, V. N., Popoykova, A. I., and Denisov, E. T. "Collection and Critical Evaluation of Rate Constants of Chemical Reactions," 794-796

Section: H

Subjects: Rate constants; Kinetic constants; Critical compilation

A report is made on the work of the Commission for Collecting and Evaluating the Rate Constants of Chemical Reactions of the Scientific Council on Kinetics, Catalysis and Reactivity. Information is presented on reference works devoted to kinetic constants that have been published and are in preparation for publication.

Kondrikov, B. N. and Sidorova, T. T. "Combustion of Nitrates and Nitrites," 58-62

Section: I

Subjects: Combustion, nitrates, nitrites; Nitrate combustion; Nitrite combustion

The combustion of nitrates and nitrites of ethanol, 1,2- and 1,3-propylene-glycol and 1,3- and 2,3- and 1,4-butylene-glycol as well as of erythritol ester, mannitol ester and glycidic ester were studied using a constant-pressure bomb. Confirmed was the deduction that the first stage of combustion is the decay of the ester with the formation of NO, NO_2 and organic products. Among the latter a special part is played by formaldehyde. The esters whose decay results in the formation of many formaldehydes burn faster. The possible reason for this is the formation of atomic hydrogen when CH_2O reacts with a radical. Some specific features of the combustion of erythritol and mannitol nitrites were detected. At 150-200 atm the usual relation $u = Bp$ is replaced for them by the stronger dependence $u = Bp^{1.5}$. At ~ 250 atm the rate again becomes almost directly proportional to the pressure. It was noted that these two nitro-esters, as well as glycidic nitrate have a very low combus-

tion stability at 1 to 100 atm, although the combustion rate is high, while nitromannitol is capable of burning even in vacuum. The reason for this, probably, is the thermal instability of their combustion, as advanced by Ya. B. Zel'dovich.

Korchunov, Yu. N. and Pomerantsev, V. V. "Mechanism of the Process of Ignition of Natural Solid Fuels," 191-194

Section: B

Subjects: Ignition, solid fuels; Solid fuel ignition mechanism

Presented in this report are the principles of the method of analyzing the process of ignition of natural solid fuels. It is shown that analysis of the ignition process must be carried out on the basis of modern concepts as to the dynamics of thermal decomposition of the organic mass of the fuel. On this basis it is necessary to examine in time, as a function of the temperature situation, the conditions of formation of the mixture of *volatiles* and *oxidizers* in the immediate neighborhood of the fuel particles and in the volume. Knowing the quantitative and qualitative characteristics of this mixture and the conditions of their variation in time, it is possible to determine the nature of the variation of its ignition induction period as a function of time and, on this basis, the instant of onset of intense oxidation of the volatiles being released. Considered as an example are the conditions of ignition of particles of peat of 0.1 and 1.0 mm in size when they hit a constant-temperature medium.

Koroban, V. A., Chugunkin, V. M., and Loboda, V. I. "Thermal Decomposition of Perchlorates of Methyl Substituted Ammonium Ions," 775-779

Section: H

Subjects: Perchlorate decomposition; Kinetic mechanisms

The kinetics of thermal decomposition of mono-, di-, tri- and tetra-methyl ammonia in the 170-340° range and as a function of the degree of filling of the reaction vessel (m/V) are investigated by the manometric method. A decrease in the decomposition rate is found with increasing m/V for the first three substances. The hypothesis is that the decrease is due to the different solubilities of the dissociation products in the salt and to decomposition of the perchloric acid primarily in the condensed phase. On the basis of this hypothesis an analysis is made of the kinetic decomposition scheme and the difference in activation energies of decomposition is explained for low ($2 \cdot 10^{-3}$ g/cm^3) and high ($3 \cdot 10^{-2}$ g/cm^3) m/V, the values of which are 42.37, 43.47, and 36.48 kcal/mole respectively for mono-, di-, and tri-methyl ammonia. It is shown that the rate of decomposition of the salts decreases with decreasing number of mobile hydrogen atoms in the cation. The final composition of the gaseous decomposition products of all the salts is given.

Koroban, V. A., Svetlov, B. S., and Chugunkin, V. M. "Low Temperature Ammonium Perchlorate Conversion Reactions," 741-744

Section: H

Subjects: Ammonium perchlorate; Decomposition of NH_4ClO_4; Kinetic mechanisms

An ammonium perchlorate decomposition scheme is examined which includes the stages of dissociation of the salt into $HClO_4$ and NH_3, decomposition of the acid, and the interaction of the $HClO_4$ decomposition products with the NH_4^+ ion. Data are given on the decomposition of the ammonium perchlorate as being governed by the decomposition of the perchloric acid that forms in the volume of the crystals, and not on the outer surface. It is shown that the $HClO_4$ decomposition product, chlorine oxide, reacts with the ammonium perchlorate in the presence of small quantities of moisture and 50% perchloric acid even at 70° C, the composition of the products of this reaction corresponding in the latter case to the composition of the products of ammonium perchlorate decomposition in the low temperature region. On the basis of the data it is concluded that the principal ammonium-perchlorate decomposition reactions take place in the condensed phase.

Korobeynichev, O. P., Shkarin, A. V., and Shmelev, A.S. "Catalysis Mechanism in the Thermal Decomposition and Combustion of Ammonium Perchlorate," 752-755

Section: H

Subjects: Catalysis; Decomposition; Ammonium perchlorate; Kinetic mechanisms

Results are presented of the study of the kinetics and mechanism of catalytic and non-catalytic decomposition of $NH_3 + HClO_4$ mixtures (by means of a time-of-flight mass spectrometer) and of ammonium perchlorate at 300-450° C. The rate constants of the catalytic reactions are determined and a quantitative relationship between these processes in the presence of catalysts is found. Proofs are presented that high-temperature decomposition of pure ammonium perchlorate takes place to a greater degree in the condensed phase. The kinetic data obtained are used to construct a model of ammonium perchlorate combustion and combustion catalysis. The results of a computer calculation of the pressure dependence of the combustion rate by this model agree with experiment at 20-100 atm.

Kossoy, A. A., Ozerov, E. S., and Sirkunen, G. I. "Burning of an Evaporating Composite Particle of a Two Component Combustible Containing Metal," 207-211

Section: G

Subjects: Composite particle burning; Burning of evaporating particle

Studied is the problem of ignition and burn-up of a hydrocarbon bond of a particle of a two-component combustible containing metal. It is presumed that heat-up of the particle is uniform over the radius; the hydrocarbon evaporates from

the surface, going deep into the particle with time; there is no reaction in the pores of the dry layer; the concentration and temperature fields in the film and the concentration field in the dry layer are quasi-stationary. It is shown that the ignition limit of a hydrocarbon bond is somewhat higher than that of a drop of pure hydrocarbon; in approximate calculations of the burning time of the bond, it can be assumed that the diffusion burning regime takes place immediately after introduction of the particle into the heated gaseous medium.

Krivulin, V. N., Lovachev, L. A., Baratov, A. N., and Makeev, V. I. "Investigation of the Influence of Acceleration on the Ignition Concentration Limits," 296-298

Sections: E, B

Subjects: Ignition concentration limits; Flame propagation, acceleration effect

Presented in this paper are the experimental results of investigating the influence of acceleration on the ignition limits of natural gas in air. The experiments were carried out in a rotating reaction-vessel apparatus. It was established that when the flame propagates with the acceleration vector, the ignition limits are narrowed, and upon reaching an excess load of $100g_0$ ($g_0 = 9.8$ m/sec^2), the combustible mixtures lose the capability of propagating flame, whereas when the flame propagates against the acceleration vector, the ignition limits are weakly dependent on the excess load.

Kuzin, A. F., Yankovskiy, V. M., Apollonov, V. L., and Talantov, A. V. "Influence of the Initial Temperature on the Basic Characteristics of Combustion in a Turbulent Flow of a Homogeneous Mixture," 337-341

Section: G

Subjects: Turbulent flame propagation; Homogeneous mixture combustion; Temperature

The data of an experimental investigation of the temperature dependence of the extent of the combustion zone, its time and the rate of turbulent flame propagation are presented. The object of investigation was a plane (turbulent) flame jet of a homogeneous benzene-air mixture. The range of investigation was $T_0 = 393$ - 793°K, $\alpha = 0.4$ - 1.9, w = 30 - 75 m/sec, and C = 4.7%. The experiments permitted determination of the following:

1. The temperature of the free stream exerts an appreciable effect on the fundamental combustion characteristics.
2. The rate of turbulent flame propagation increases with increasing free-stream temperature, while the duration and extent of the combustion zone decreases.
3. The degree of influence of the initial temperature on the combustion characteristics decreases with increasing initial velocity.

An analysis of the results of investigations was made on the basis of a surface model of turbulent burning, showing good agreement between the theoretical results and the experimental data.

Kuznetsov, V. R. "Influence of Fluctuations of Temperature and Concentration on Ignition Delay in a Turbulent Flow," 342-346

Section: **B**

Subjects: Ignition delay; Turbulent flow; Temperature fluctuations; Concentration fluctuations

Analyzed in this paper is the influence of fluctuations of temperature and concentration on the self-ignition delay in the mixing layer of unbounded flows of hot air and cold hydrogen. In averaging the chemical reaction rate, use is made of a model of the probability distribution function based on the intermittent nature of the flow near the boundary with the hot flow. The equation of turbulent diffusion, obtained assuming a constant transfer coefficient over the fully turbulent fluid, is used in calculations of the ignition delay.

It is found that fluctuations in temperature and concentration increase the ignition delay by a factor of 2-3. This is associated with the fact that the chemical reactions take place only in a fully turbulent fluid, and the mean temperature of this fluid is below the average (in the usual sense) temperature. The influence of the various parameters on the ignition delay is analyzed.

Lapshin, A. I., Lazárenko, T. P., Stupnikov, V. P., and Batsanov, S. S. "On Irreversible Changes in the Properties of Crystallophosphors as a Result of Explosive Action," 533-539

Section: I

Subjects: Crystallophosphors; Explosive action; Luminescence; Triboextinction

An experimental study is made of the effect of explosive stress on the spectral-luminescence properties of industrial and laboratory phosphors, produced on a base of ZnS, ZnSe, CdS, and their solid solutions: tungstates, silicates, phosphates, fluorgermanates, etc. The overall result of explosive treatment of crystallophosphors is their triboextinction spectral shifts and broadening of the radiation bands, changes in density, energy distribution of the capture centers, and thermal extinction temperatures. Such residual changes of the phosphors are connected with macroscopic transformations of crystals by cleavage and the formation of microcracks, leading to a lowering of the concentration of radiation centers and to intensified scattering of the exciting and radiating light, and by microscopic changes in the structure of the matrices of the basic material, the microstructure of the radiation centers, leading to spectral shifts of the luminescence bands, and with the formation of capture and extinction centers.

Lebedev, B. P. and Doktop, I. Yu. "Stabilization of the Flame of Inhomogeneous Mixtures," 361-364

Section: G

Subjects: Flame stabilization; Inhomogeneous mixtures

An experimental study is made of the process of stabilizing the flame of an inhomogeneous kerosene-air mixture with a high fuel content in the vapor phase (velocity of $w = 100\text{-}180$ m/sec, pressure of $p_o = 0.2\text{-}0.6$ atm, gas temperature of 650°C). It was found that the mechanism of stabilization of the flame of the inhomogeneous mixture behind a poorly streamlined body is no different in principle from that for a homogeneous mixture. The variable which governs the boundaries of the region of stable combustion of an inhomogeneous mixture is the excess-air coefficient in the circulation zone behind the stabilizer, α_{st}. The characteristics of the boundaries of the stable combustion region are generalized by the relation

$$w/dp_o = f(\alpha_{st}) ,$$

where d is the characteristic size of the stabilizer.

Lebedev, S. N., Leonas, V. B., Malama, Yu. G., and Osipov, A. I. "Use of the Monte Carlo Method in Chemical Kinetics," 702-711

Section: H

Subjects: Tritium; Methane; Hot atoms; Monte Carlo method

A nonlinear scheme of the Monte Carlo method is used to solve spatially homogeneous problems in chemical kinetics. Disruption of equilibrium distributions by chemical reactions in gas systems and the influence of such disruptions on reaction rates are investigated. The convergence of solutions of the corresponding gaskinetic Boltzmann equations was verified in a number of cases by the Chapman-Enskog method. The inverse problem of the chemistry of hot atoms was considered: the parameters of excitation functions of two types of reaction of the tritium atom with a methane molecule were calculated.

Lisitsyn, V. I., Pirozhenko, A. A., and Vilyunov, V. N. "Induction Period in the Ignition of a Disperse System," 186-190

Section: B

Subjects: Induction period; Ignition, dispersed system; Disperse system induction

The criteria of applicability of the stationary heat transfer coefficient for description of heat exchange between particles and a gas are discussed. Quasistationary propositions on the course of the inert (due to radiation) and chemical pre-heating form the basis for an analysis of ignition by a radiant energy flux. Temperature profiles of both stages are cross-linked to within the continuity of the first derivatives. The process can take place under ignition or inflammation conditions, when

the heat losses within the cold layers are not great. In the case of ignition by an incandescent surface, the time of conversion of the surface from a heat source to a sink is determined. Curvature of the surface does not affect processes in the chemical boundary layer and takes on fundamental significance for the pre-heating zone: critical conditions appear. The agreement between numerical calculations on a computer and approximate calculations is satisfactory in both modes.

Letyagin, V. A., Solov'ev, V. S., Boyko, M. M., and Kuznetsov, O. A. "Investigation of the Initiation of Liquid Explosives by Means of a Capacitive Sensor," 498-503

Section: B

Subjects: Liquid explosives; Capacitive sensor initiation

The initiation of liquid explosive solutions with a tetranitromethane base is studied experimentally using a capacitive sensor. The explosive was placed between plates, one of which was an attenuator. This method makes it possible to measure the delay time in both straight and reflected shocks. It is possible, simultaneously with the delay time of the explosion, to measure the velocity of the attenuator-explosive interface and the detonation velocity of the explosive after development of the boundary. The application of the method was preceded by a thorough analysis of the accuracy. In the worst case the experimental error did not exceed 10%.

Leypunskiy, O. I., Zenin, A. A., and Puchkov, V. M. "Influence of a Catalyst on the Characteristics of the Combustion Zone of a Condensed Substance," 74-77

Section: I

Subjects: Combustion of condensed substances; Catalyst influence on combustion zone

Measurements were made of the temperature distribution over the combustion zone in the condensed and gaseous phases of model mixtures of polymethylmethacrylate with finely dispersed ammonium perchlorate with an addition of 1% Fe_2O_3 and without the additive and of a rubbery binder with ammonium perchlorate with additions of 1% Fe_2O_3 and 3.8% of ferrocene and without additives. An analysis of the experimental data shows that these substances yield a catalytic effect in both the surface layer and in the main volume of the gas phase, but only the catalytic effect in the surface layer works to increase the combustion rate.

Librovich, V. B. and Makhviladze, G. M. "Propagation of a Low Amplitude Wave Over the Surface of a Powder Burning in a Gas Stream," 110-114

Section: H

Subjects: Low amplitude wave propagation; Burning powder

Examined is the wave mode of powder combustion caused by entrainment of the gasification products by the gas stream. It is shown that a periodic wave whose amplitude, generally speaking, changes in accordance with the direction of propagation can propagate over the surface of the powder.

The wave velocity, its dependence on the wave length, powder burning rate and drag coefficient of the gas stream in the duct of the charge of powder are determined. The entire examination is based on a theoretical model of non-stationary powder combustion proposed by Ya. B. Zel'dovich.

Losev, S. A. "Study of the Kinetics of Physico-chemical Processes in Shock Tubes," 672-678

Section: H

Subjects: Kinetics; Shock tube

The qualitatively new facts among the results of shock-tube experiments are: (1) the detection of a transition from an adiabatic mechanism of vibrational excitation of diatomic molecules (iodine, bromine) to a non-adiabatic one; (2) pumping in mixtures of diatomic gases during vibrational exchange; (3) variation in the time of vibrational relaxation owing to the anharmonicity of the molecules; and (4) variation in the rate constant of dissociation in the absence of vibrational equilibrium. Characteristics of the research of recent years is the use of a complex method with which several parameters of a system are measured simultaneously. Research of processes in nozzles mounted on the butt end of a shock tube has been advanced appreciably. In a number of papers inadequate attention is paid to an analysis of the measurement errors. Mathematical methods must be developed for the solution of the so-called inverse problems, in which the rate constants of elementary processes are determined from the results of measuring concentrations.

Lovachev, L. A. and Gontkovskaya, V. T. "On the Role of Nonlinearity in the Hydrogen Oxidation Scheme," 638-641

Section: H

Subjects: Hydrogen oxidation; Kinetics; Hydrogen; Oxygen; Ignition

A system of isothermal kinetic equations for OH, H, O, HO_2, H_2O_2, H_2, O_2 and H_2O is solved on a computer. The development of oxidation during the self-ignition delay period at pressures near the second and third limits is governed by elementary processes with the participation of HO_2. The rate of hydrogen oxidation in lean mixtures after the self-ignition delay period does not depend on the rate constant of the branching process $H + O_2 \rightarrow OH + O$.

Manelis, G. B. and Strunin, V. A. "Mechanism of Combustion of Ammonium and Hydrozonium Salts," 53-57

Section: G

Subjects: Combustion mechanism, of salts; Ammonium hydrozonium salt combustion

The processes of exothermal decomposition of a substance in the condensed phase and of simultaneous evaporation form the basis of the mechanism of combustion of these compounds. The pressure dependence of the combustion rate is governed by two factors: temperature increase of the combustion surface and change in concentration of the dissociation product of the original salt, accelerating the reaction. The expressions obtained for the combustion rate, pressure coefficient, temperature coefficient and steady combustion stability criterion are in qualitative agreement with experimental data.

Marchenko, G. N., Moshev, V. V., Batyr, D. G., Borisov, S. F., and Pogonin, G. P. "Influence of Structural Factors on the Catalytic Activity of β-Diketonates of the 3d Shell Elements in the Thermal Decomposition of Ammonium Perchlorate," 759-764

Section: H

Subjects: Decomposition of NH_4ClO_4; Ammonium perchlorate; β-diketonates; Kinetic mechanisms

A study is made of the influence of a broad range of β-dicarbonyl compounds of transition metals on the rate of non-isothermic decomposition of ammonium perchlorate. It is shown that the catalytic activity of the compounds being examined during decomposition of ammonium perchlorate depends on the nature of the central atom of the metal as well as on the structure and properties of the organic ligand.

A satisfactory correlation is established between the catalytic activity of the β-diketonates in the thermal decomposition of ammonium perchlorate and the total Taft induction constant of the substitutes in the B-diketone, this constant being an indirect characteristic of the degree of localization of the electron density on the central ion of the generator of the metal complex.

On the basis of the data obtained a scheme is proposed for the mechanism of catalytic decomposition of ammonium perchlorate which assumes the participation of the catalyst in the low-temperature stage of the decomposition of ammonium perchlorate with the formation of $HC10_4$ and NH_3.

Margolin, A. D. "Contemporary Status and Some Problems in the Theory of Combustion of Condensed Systems," 5-14

Section: G

Subjects: Combustion, condensed systems; Condensed systems, combustion of

A brief review is given of the status of the theory of stationary and nonstationary combustion of homogeneous solid, liquid and two-phase systems and of the regulation of the combustion rate.

Merzhanov, A. G., Gal'chenko, Yu. A., Grigor'ev, Yu. M., and Mashkinov, L. B. "Ignition of an Aluminum Wire," 245-249

Section: **B**

Subjects: Ignition, aluminum wire; Aluminum wire ignition

The ignition of an aluminum wire in a stream of pure oxygen at atmospheric pressure is studied by the electrothermographic method. The ignition temperatures and the critical electrical power are determined as a function of the gas flow velocity and wire diameter. A relation is obtained for the ignition parameters as a function of the initial thickness of the oxide film on the wire for various methods of film application.

Mineev, V. N., Ivanov, A. G., and Tyunyaev, Yu. N. "Electrical Effects During Shock Compression of Conductive Materials," 597-601

Section: I

Subjects: Shock compression; Acoustoelectric effect; Shock polarization; Contact potential; Piezoelectric effect

The emf that arises during shock compression of specimens of tungsten, antimony, cadmium, beryllium, and lead is detected and studied. The possible sources of this emf are examined: (a) internal contact difference in potentials; (b) deformation of the twofold surface electric layers in the shock wave; (c) breakthrough of the current carriers by inertia at the shock front; (d) the acoustic-electric effect; (e) shock polarization. Proofs are presented that in a number of cases the observed emf is connected with mechanisms (a) and (e).

Muratov, S. M., Makharinskiy, V. M., Afanas'ev, G. T., and Postov, S. I. "Ignition of Pyroxylin at High Pressures and Temperatures," 30-33

Section: **B**

Subjects: Ignition; Pyroxylin

A specially developed method is used to study the ignition of pyroxylin at high temperatures and pressures. The experimental conditions correspond to a problem set up as ignition of an explosive by an infinite body with a flat surface (boundary conditions of the fourth kind). Relations are obtained for the ignition lag time in the interval 10^{-5} to 10^{-3} sec as a function of the inverse temperature. The experimental results are compared with literature data. The possible reasons for the increase in lag time with increasing pressure are discussed.

Nedin, V. V., Neykov, O. D., Alekseev, A. G., Vasil'eva, G. I., and Kostina, E. S. "Study of the Combustion of Gas Suspensions of Metal Powders and of the Influence of Particle Size on the Parameters of Explosiveness," 195-198

Section: G

Subjects: Combustion, metal powders; Explosiveness, metal powders; Metal powders in gas suspensions

Given are the results of investigations (by the methods of the Inst. for Appl. Mineralogy of the Acad. Ski., Ukrainian SSR) of the principal pyrophoric and explosive characteristics of gas suspensions of powders of reduced iron and electrolytic titanium of varying degree of dispersion. Determined are the lower concentration limit of explosiveness, the explosion pressure, the rate of pressure rise, the minimum ignition temperature, and other parameters.

Nesterko, N. A., Taran, E. N., and Tverdokhlebov, V. I. "On the Mechanisms of Ion Recombination in a Low Pressure Hydrocarbon Flame," 737-740

Section: H

Subjects: Ion recombination; Hydrocarbon flame; Electron-ion recombination

An examination is made of the dependence of the recombination coefficient on the pressure, composition of the mixture and flame-gas temperature in an acetylene-air flame at pressures ranging from 14 to 100 mm Hg. It is found that in this pressure range the recombination coefficient is pressure-independent. When the temperature changed from 980 to 1870° K, the recombination coefficient changed according to the low $\alpha \sim T^{-(1.5-1.6)}$. It is concluded that dissociative electron-ion recombination takes place in hydrocarbon flames that are nearly stoichiometric in composition. From the dependence of the recombination coefficient on the composition of the mixture it is deduced that in such flames, in addition to electron-ion recombination, an appreciable role in the decomposition of the flame plasma is played by ion-ion recombination.

Nigmatulin, R. I. and Vaynshteyn, P. B. "Flame Propagation in a Gas Mixture with Particles," 182-185

Section: D

Subjects: Flame propagation; Particles, heterogeneous combustion; Gas mixtures, particles, combustion of

The particular features of formulation of the problem of stationary flame front propagation in gas suspensions are discussed. In particular, for the case of purely heterogeneous combustion of particles, the nature of the singular points corresponding to equilibrium states is investigated. It is shown that the asymptotic behavior of the particle parameters behind the flame front depends on the composition of the fresh mixture.

Nikiforov, V. S. and Bakhman, N. N. "Influence of Aluminum Additives on the Effectiveness of an Fe_2O_3 Combustion Catalyst," 70-73

Section: I

Subjects: Aluminum additives; Fe_2O_3 combustion catalyst

A study was made of the influence of aluminum additives on the effectiveness of a catalyst (1% Fe_2O_3) during the combustion of mixtures of ammonium perchlorate and potassium perchlorate with polystyrene and polymethylmethacrylate.

For mixtures on an ammonium perchlorate base with an excess of oxidizer or a large excess of fuel the catalyst has a strong effect on the original mixture (without Al), but its effectiveness is reduced when Al is introduced. In contrast, for mixtures not too far from stoichiometry the catalyst has a weak effect on the original mixture, but its effectiveness increases when Al is introduced.

In mixtures on a base of potassium perchlorate without Al as well as with additions of finely dispersed Al, the ferric oxide is ineffective.

Novitskiy, E. Z., Ivanov, A. G., and Khokhlov, N. P. "Investigation of the Shock Polymerization of Polymers," 579-584

Sections: H, I

Subjects: Shock polymerization; Polymers; PVC; Teflon; Polyethylene; "Plasticate"

Comparative experiments were made on a number of polymers (polyvinylchloride, plasticate, polyethylene, polytetrafluoroethylene, et al.) and molding powders. Inherent in all of them are the features of shock polarization of linear dielectrics: a jump in current at the instant of shock wave entry into the specimen, a growth or fall-off in current (depending on the nature of the behavior of the dielectric permittivity behind the shock front) as the shock wave passes through the specimen, a sharp drop in current at the instant the shock wave leaves the specimen. No correlation between the characteristics of the polymers and the shock polarization was found. The specific features of polarization of molding powders with a quartz filler (current oscillation) and of porous polystyrene (distinctly pronounced density dependence of the polarization current) are noted.

Novitskiy, E. Z., Tyun'kin, E. S., Mineev, V. N., and Kleshchevnikov, O. A. "Study of Shock Wave Properties and of Polarization by TsTS-19 Piezoceramics," 602-607

Section: I

Subjects: Shock wave; Polarization; TsTS-19; Piezoceramics

The Hugoniat adiabat is obtained in the 5-1000 kbar pressure range at $p = 20 \pm 2$ kbar. A discontinuity is observed in the adiabat; it is identified with the Hugoniot yield point. A two-wave configuration exists at $p = 20 - 200$ kbars.

For the elastic pressure region an analysis is made of the depolarization current curves of piezoceramic discs. It is shown that the shape of the current is greatly

dependent on the relationship between elements of the measurement loop: the capacitance of the load resistance discs and the inductance of the assembly.

The pressure dependence of the electrical charge realized during loading is considered on the basis of the particular features of the behavior of porous materials behind a shock front. Values are given for the internal resistance of the discs, as obtained by the method of selecting optimal power per load.

Ordzhonikidze, S. K., Margolin, A. D., and Pokhil, P. F. "Combustion of Condensed Explosives under Accelerating Loads," 83-86

Section: G

Subjects: Condensed explosives; Combustion of explosives, influence of accelerating loads

The influence of accelerating loads on the combustion of solid, liquid, and water-filled explosives was studied experimentally. Under the influence of the acceleration the combustion rate of solid aluminized substances increases; the critical pressure of transition from laminar to turbulent combustion of liquid and water-filled systems increases. A theoretical expression was obtained for the minimum and maximum combustion rates of an aluminumized substance.

Panin, V. F., Parfenov, L. K., and Zakharov, Yu. A. "Phenomenon of Three Flame Propagation Limits on the System H_2 - O_2 - N_2," 293-295

Sections: E, G

Subjects: Flame propagation limits; H_2 - O_2 - N_2 systems

The concentration limits of flame propagation in hydrogen-oxygen-nitrogen mixtures in the pressure interval of $\sim$10-10^3 mm Hg were studied experimentally. The existence of two (pressure) limits of flame propagation was established: for a given O_2 content in the system, flame propagation at a certain H_2 concentration is possible only in a specific pressure interval. Analysis of the results of experiments and of data from literature sources have made it possible to conjecture the existence of three limits (pressure) of flame propagation in the H_2-O_2-N_2 system. A hypothetical schematic picture of the limits for the system in the 10-10^5 mm Hg pressure interval is given.

Pervitskaya, T. A., Skabin, A. P., and Tarasyuk, V. A. "Approximate Methods of Studying Diffusion Burning in a System of Turbulent Jets," 352-356

Section: G

Subjects: Diffusion burning; Turbulent jets

Considered is a system of jets of hot components issuing from parallel ducts (flat or round) arranged in a specific order, with thin walls. By introducing gener-

alized von Mises variables and linearization, the problem is reduced to solution of the thermal conductivity equations with all the gas-dynamic quantities prescribed as having rectangular profiles at the entrance to the combustion zone. A simple relationship is established between the longitudinal pressure gradient ($\triangle p$) and the completeness-of-combustion coefficient (η):

$$\eta = \triangle p / \triangle p_\infty ,$$

where $\triangle p_\infty$ is the gradient for complete burn-up of the deficient component.

An analysis of measurements of the completeness-of-combustion coefficient made by various authors made it possible to establish a sufficiently general relationship between this coefficient and the inlet parameters in the case of an axisymmetric flow:

$$\eta = 1 - e^{-ax^2} ,$$

where x is the longitudinal coordinate and a is a coefficient determined by the geometry, the density ratio, and the stoichiometric coefficient.

Potekhin, G. S., Baratov, A. N., Makeev, V. I., Prokhorov, N. S., Pankratov, I. P., and Rozantseva, G. V. "Flegmatization of Detonation and Deflagration Combustion of Kerosene Air and Kerosene Oxygen Systems," 491-493

Section: G

Subjects: Detonation flegmatization; Deflagration combustion; Kerosene-air system; Kerosene-oxygen system

The results of an experimental study of the flegmatizing capability of tetrafluorodibromomethane (TFDBM) applied to a gaseous homogeneous kerosene air system and to a heterogeneous solid liquid system of solid kerosene and liquid oxygen are presented in this communication. The inflammability limits of the kerosene air gas phase system are determined. Data are obtained in the flegmatization by TFDBM of a homogeneous burning and a heterogeneous detonating kerosene oxygen system: it was found that complete flegmatization sets in when the content of TFDBM is about 28-30% by weight in the condensed system and 75% in the gaseous system.

Raevskiy, A. V. and Manelis, G. B. "Development of Reaction Centers in the Thermal Decomposition of Orthorhombic Ammonium Perchlorate and the Role of Dislocations in this Process," 748-751

Section: H

Subjects: Reaction centers; Thermal decomposition; Ammonium perchlorate; Dislocations; Kinetic mechanisms

A microscopic investigation is made, directly during reaction, of the particular features of the development of reaction centers in the thermal decomposition of

crystals of orthorhombic ammonium perchlorate. The temperature dependence of the width of the chemical reaction zone (in the [010] direction) for individual centers (activation energy around 10 kcal/mole) is determined. The pressure of the gaseous reaction products in individual nuclei is found (about 20 kp/cm^2 at 225°C). The hypothesis is advanced that the reaction takes place both at stationary dislocations (induction period) and at decomposition centers moving in the reaction zone.

Romanov, O. Ya. and Shelukhin, G. G. "Contribution to the Theory of Stability of Powder Combustion," 94-99

Section: G

Subjects: Combustion of powder; Powder combustion, stability of

Using a method developed by Ya. B. Zel'dovich and B. V. Novozhilov the stability of powder combustion is investigated, taking into account the inertia of the processes taking place in the condensed phase (K-phase), including the reaction zone.

The stability of combustion is contingent in this case on the values of the four dimensionless parameters which reflect the influence of the initial temperature on the stationary values of the combustion rate, temperature, and concentration of the material on the surface of the K-phase, as well as the fraction of heat released as a result of a zero-order chemical reaction contained in the total volume of heat in the K-phase.

The following were found: the ranges of stable combustion and vibrational relaxation modes of the nonstationary combustion rate are expanded and the vibrational frequencies of the combustion rate are decreased compared to those in the powder model investigated by B. V. Novozhilov.

Rubtsov, Yu. I. "Kinetics and Mechanism of Thermal Decomposition of Hydrazonium Salts," 771-774

Section: H

Subjects: Kinetic mechanisms; Decomposition, hydrazonium salts; Hydrazine

The kinetics of thermal decomposition of hydrazonium nitrate, chloride, iodide, azide, and perchlorate is examined. It is demonstrated that in all cases the reaction takes place via equilibrium dissociation of the original salt in the liquid phase into hydrazine and the corresponding acid, while the reaction rate is governed by the rate of decomposition of the products of this dissociation. Two different mechanisms are experimentally observed for such a reaction: thermal decomposition of the complex $N_2H_4 \cdot N_2H_5^+$ and interaction of the molecules of the acid with the original salt.

Rumanov, E. N. and Khaykin, B. I. "Regimes of Flame Propagation through a Suspension of Particles in a Gas," 161-165

Section: D

Subjects: Flame propagation; Particle suspension

The combustion of a gas suspension when the front reaction zone is formed by particles reacting in a diffusion region is examined. The heat transfer into the cold suspension can be conductive or radiant. In the latter case, the velocity of the front is inversely proportional to the concentration of the particles when the combustion is fast, so that the gas does not succeed in heating up enough to ignite the particles. A relationship is found between the rate of combustion and the particle size and combustion limits. the possibility of transition of one type of heat transfer into another where the system parameters are varied is studied.

Rybanin, S. S. "Theory of the Combustion of Fuel Droplets in a Stationary Medium and a Flow of Oxidizers," 212-220

Section: G

Subjects: Fuel droplet combustion; Droplet combustion, stationary medium; Droplet combustion, oxidizer flow

A method is outlined for solving equations describing the burning of a drop of fuel in an oxidizer atmosphere. Cases of the quasi-stationary combustion of a drop in a stationary atmosphere and in an oxidizer flow are examined. Typical interrelations between the parameters of this process are illustrated. The critical conditions of ignition and extinction of the drop are obtained.

Salamandra, G. D. "Flame Propagation in a Transverse Electrical Field," 309-312

Section: G

Subjects: Flame propagation; Transverse electrical field

The influence of a transverse electrical field on the process of flame propagation in horizontal pipes filled with a methane-air mixture containing 10% CH_4 is investigated. Two combustion regimes are studied: flame propagation at constant velocity when the mixture is ignited at the open end of the pipe and combustion in a pipe closed at both ends. Experiments in a pipe with electrodes insulated from the flame were duplicated by experiments in which the electrodes were set flush with the upper and lower walls of the pipe. The influence of an electric field on flame propagation through narrow ducts and slits was studied in a pipe of variable cross section. A number of features of the development of the combustion process in a transverse electrical field was detected: displacement of the leading edge of the flame toward the negatively charged plate, increase in flame surface area owing to extension of the flame front and the appearance of wrinkles on its surface, the appearance of a "travelling wave" type perturbance on the surface of the flame, etc. It is shown that the passage of current through the flame does not change the features of the combustion process that were observed in experiments with insu-

lated electrodes. Only the capacity of the flame to become longer decreases, as does the magnitude of the threshold value of the field strength at which a change in structure of the flame front begins. It is shown that the electric field is a convenient physical means of manipulating a flame, permitting both intensification of the combustion process (when the flame propagates in pipes of sufficiently large cross section) and flame extinction (in narrow pipes).

Salamandra, G. D., Ventsel, N. M., and Fedoseeva, I. K. "Measurement of Gas Velocity During the Ignition of Fast Burning Gas Mixtures in Pipes," 370-373

Section: B

Subjects: Gas velocity, measurement; Ignition, gas mixtures

Described in this report are methods of measuring gas velocity, and some results obtained by means of these methods are presented. The velocity of the fresh gas was determined from the motion of artificially created thermal inhomogeneities (tracers). Particular attention was devoted to a description of the method of extracting tracers suitable for measuring the velocity of a medium moving with high acceleration. The velocity of the reaction products behind the flame front was measured from the motion of visible inhomogeneities arising from a high-frequency spark discharge. The velocity of the reaction products behind the detonation wave was measured from the motion of the shear surface that arises when the detonation wave reacts with the shock wave formed in the stage of accelerated flame propagation near the closed end of the pipe.

Savintsev, Yu. P., Mulina, T. V., and Boldyrev, V. V. "Mechanism of the Low Temperature Thermal Decomposition of Ammonium Perchlorate," 756-758

Section: H

Subjects: Decomposition of NH_4ClO_4; Ammonium perchlorate; ClO_2; $HClO_4$

It is proposed that the process of formation of nuclei in the thermolysis of ammonium perchlorate takes place as a result of thermal dissociation and subsequent secondary reactions, while the growth of nuclei is associated primarily with secondary stages. In order to verify this assumption a microscopic study is made of the influence of doping with divalent ions and of decomposition in an atmosphere containing ammonia on the rate of formation and growth of nuclei. Data are obtained which confirm the hypothesis. Further evidence of its validity is the presence of localization during the thermolysis of the ammonia salts formed by oxidizer acids, the difference in activation energy of formation and growth of nuclei, and the acceleration of nucleus-formation of nuclei under the effect of ClO_2.

A mechanism is developed for the formation of nuclei owing to the generation of excess concentrations of $HClO_4$ in the empty dislocation core. Data are obtained on the increased activity of screw dislocations during sublimation of the salt.

Selezneva, I. K. "Spherically Symmetrical Optical Discharge as an Analog of Diffusion Combustion in Fuel Gas Mixture," 396-400

Sections: I, G

Subjects: Diffusion combustion; Optical discharge

A theoretical investigation is made of diffusion burning on the surface of a spherical gas volume under the assumption of an infinitely narrow reaction zone. Considered in an analogous formulation is the "combustion" of a spherically symmetrical optical discharge sustained by a source of coherent radiation whose power is lower than the threshold power for breakdown. Stationary relations are obtained. The stability of the two models to radial perturbations is studied.

Selivanov, V. F., Vlasenko, I. V., Stepanov, R. S., and Gidaspov, B. V. "Principles of the Thermal Decomposition of β-Polynitroalkyamines and Amides," 789-793

Section: H

Subjects: β-polynitroalkyamines; Amides; Decomposition; Kinetic mechanisms

The statistical method using Bourdon manometers is applied to the study of the kinetics of thermal decomposition in a melt of trinitrotoluene and dibutylphthalate of the β-polynitroalkyamine series (PNA) of the general formula

$$R_1NHCHR_2C(NO_2)R_3\ ,$$

where R_1 is C_6H_4X, -COCH, or iso-COC_6H_5; R_2 is H, CH_3, C_3H_7, iso-C_3H_7, $CH_2C_6H_5$, $CH_2CH_2C(NO_2)_3$, or CH_2Cl; and R_3 is H, CH_3, CN, NO_2, or Cl. The rate constants are calculated in the initial portion of gas generation, not complicated by autocatalysis. The range of the activation energy is -20 + 35 kcal/mole, that of the pre-exponential factor is $-10^7 + 10^{14}$. The influence of structural factors on the rate of thermal decomposition is the same as in β-anionic decomposition of PNA in aqueous solutions that goes on to rupture of the carbon-carbon bond. It is concluded that the thermal decomposition of PNA under the experimental conditions proceeds according to a single mechanism and begins with rupture of the C-C bond and the formation of a carbonium-iminium cation and a polynitroalkane anion. The secondary decomposition products catalyze the process.

Semenov, N. N. and Azatyan, V. V. "On the Role of Negative Interaction of Chains and Heterogeneous Reactions of Active Centers During the Combustion of Hydrogen," 625-633

Section: H

Subjects: Chain reactions; Heterogeneous reactions; Active centers; Combustion; Hydrogen

It is shown that during the low-pressure combustion of hydrogen, negative chain interaction, due essentially to the reaction $O + OH = O_2 + H$, plays an important

role. This reaction must be taken into account, especially when the method of quasistationary concentrations is applied, if the combustion is not small. It is indicated that surface-absorbed active center reactions must be taken into account. These reactions can take place in particular with ejection of chain carriers into the volume. The role of self-heating during combustion is examined.

Shchetinkov, E. S. "Supersonic Combustion Problems," 276-281

Section: G

Subject: Supersonic combustion

Shockless supersonic combustion (undercompressed detonation) is examined. It is shown that with a one-dimensional description of a supersonic diffusion flame jet in an expanding duct the velocity of the reaction wave can be lower than the Chapman Jouguet velocity. But the correctness of a one-dimensional treatment requires additional research, especially for the initial portion of the flame jet. A two-dimensional analysis of supersonic combustion permits a qualitative explanation for the experimentally observed growth of turbulent diffusion compared to flow without combustion. The development of computational methods that take this effect into account is being delayed by the absence of a universal physical model of turbulent mixing up to molecular scales.

Shkadinskiy, K. G. and Khaykin, B. I. "Influences of Heat Losses on Propagation of the Front of an Exothermic Reaction in the Condensed Phase," 104-109

Section: H

Subjects: Heat losses, effect on front propagation; Condensed phase reaction

The influence of heat losses on the steady-state combustion mode of gasless condensed materials is studied by means of an analytic investigation of a simplified model and numerical solution of the complete system of differential equations. It is shown that the domain of possible parameter values breaks down into four subdomains: stable stationary combustion exists in the first; stationary combustion is impossible in the second because of large heat losses; pulsating combustion occurs in the third; combustion does not take place in the fourth since stationary combustion is unstable in it, and pulsating combustion is impossible because of heat losses.

Shtern, V. Ya., Revzin, A. F., and Sukhanov, G. V. "Role of Excited Particles in the Accelerating Effect of Additions of Oxygen on the High Temperature Chlorination of Ethylene," 720-724

Section: H

Subjects: Ethylene; Chlorine; Kinetics; Acceleration; Oxygen

The kinetics and products of reaction of ethylene with chlorine at 250-385° C and the influence of oxygen on this reaction at 270-320° C were studied. Small additions of O_2 accelerate the reaction by a factor of 40-50 at a considerable increase in the activation energy; the nature of the kinetic curve, the order of the reaction with respect to components, the ratio of reaction products, and also the nature of the action of inert gases and of the surface of the reaction vessel change. The added oxygen is not essentially consumed. The data are explained by the fact that excited particles are formed in the presence of O_2, their further conversion leading to a branched chain reaction.

Shtessel, E. A., Averson, A. E., and Pribytkova, K. V. "Influence of Natural Convection on the Ignition of Liquid Explosives," 24-29

Section: H

Subjects: Convection; Ignition; Liquid explosives

This paper is devoted to an approximate theoretical analysis of ignition phenomenon, taking natural convection into account. Considered is a horizontally infinite layer of liquid of sufficiently great height. Ignition is by heating from below under two types of boundary conditions: (a) at constant surface temperature during the process; (b) at constant thermal flux. The system of equations of motion, energy and continuity is studied. As a result of the physical assumptions that have been made, it is possible to solve the problem by the method of succession approximation using the method of integral relations.

Analytic relations are obtained for the ignition delay time as a function of the Rayleigh number characterizing the intensity of convection and of the Prandtl number for the two types of boundary conditions. A number of features in the ignition process resulting from developed natural convection is examined.

Shteynberg, A. S., Ulybin, V. B., Dolgov, E. I., and Manelis, G. B. "Effect of Dispersion in the Processes of Linear Pyrolysis and Combustion of Polymers," 124-127

Sections: I, G

Subjects: Polymer linear pyrolysis; Combustion of polymers; Polymer dispersion

Experimental data are presented on thermal decomposition, linear pyrolysis, and combustion, under model conditions, of linear and crosslinked polymethylmethacrylates. It is shown that during high-temperature pyrolysis, all the way to linear K-phase decomposition rates of 0.4-0.5 mm/sec, the macrokinetics of the process are well described by the isothermal kinetics of thermal decomposition determined in the 290-370°C temperature range for conversion depths exceeding 0.5-0.6. A change in the pyrolysis mechanism takes place at linear decomposition rates exceeding 0.5 mm/sec, owing not only to a change in the kinetic mechanism of the process, but also to the increasing part played by the dispersion effect under these conditions.

Shvelov, K. K. and Koldunov, S. A. "On the Influence of the Physical State and Structure of a Trinitrotoluene Charge in the Decomposition Time in a Detonation Wave," 439-443

Section: G

Subjects: Detonation, trinitrotoluene; Trinitrotoluene detonation

The stability of the front is demonstrated; the parameters and time of the chemical reaction in a liquid TNT detonation wave are determined; results obtained earlier on the detonation and reaction time parameter in solid TNT charges of varying porosity and charge diameter are generalized and supplemented. Data are obtained on the influence of cooling of solid TNT charges by liquid nitrogen on the reaction time in the detonation wave. The shock adiabatic of TNT of 0.9 g/cm^3 density is determined. The shock adiabatic of solid trotyl of varying porosity and the temperatures of shock heating of liquid and solid trotyl of varying porosity are determined at various pressures.

Solov'ev, V. S., Andreev, S. G., Levantovskiy, A. V., Shamshev, K. N., Fedin, E. D., Tsvetkov, L. P., and Krasov, G. A. "Optical and X-ray Investigations of the Detonation Properties of Low Density Explosives with a Hexogen Base," 451-454

Section: G

Subjects: Detonation properties, hexogen; Hexogen detonation properties

A study was made of the detonation properties of hexogen suspended in mipor (microporus rubber) with a density of up to 0.05 g/cm^3. Model x-ray investigations confirmed the jet nature of the detonation front; in this case the main mass of grains explodes with a certain delay. A discrepancy between the zone of luminescence and the maximum-pressure region corresponds to this type of detonation front structure in optical studies. In the experimental density range, the relation $D = 1.46 + 4.16\rho$ was obtained. Overcompressed regimes were investigated by creating conditions in which Mach collision of detonation waves is realized.

Sosnova, G. S. "Combustion of Boron and Aluminum to High Oxides at High Pressure and Temperature," 455-458

Section: G

Subjects: Boron combustion; Aluminum combustion; High pressure and temperature combustion

Measurement of the detonation rates of composite explosives of ammonium nitrate-boron and ammonium nitrate-aluminum has shown that boron and aluminum oxidize to B_2O_3 and Al_2O_3, respectively, at temperatures of 2500 and 4000° K and pressures above 25 kbars, releasing energy from the oxidation reaction in a detonation wave. The difference in behavior of the metals during combustion is shown, based on their physico-chemical properties.

Strokin, V. N. "The Process of Ignition and Combustion of Hydrogen in a Supersonic Flow," 282-285

Sections: B, G

Subjects: Hydrogen, ignition, combustion; Supersonic flow

The results of an experimental investigation of the combustion of hydrogen delivered from the walls in a wind tunnel with $M_1 = 3.5$ at the entrance are examined. The air temperature at the tunnel entrance is $\leqslant 2{,}100°K$, the pressure $p = 0.04$ atm. It is shown that hydrogen ignition occurs at the end of the tunnel, in the wall boundary layer, and the possibility of ignition depends on the force of the perturbations applied to the flow by the fuel jets. Combustion under these conditions brings about a considerable improvement in the mixing of fuel with the air. On the basis of specific experiments it is hypothesized that the reasons for this improvement is the intense compression shocks that arise in the tunnel when heat is added to a supersonic flow.

Sukhinin, A. I. and Konev, E. V. "Combustion of Vegetable Matter for Various Compositions of the Ambient Medium," 153-156

Section: D

Subjects: Combustion of pine needles; Pine needle combustion

The characteristics of the dependence of flame propagation through pine needles upon the introduction into the ambient medium of helium, carbon dioxide, nitrogen, oxygen, as well as on the air pressure were studied. The weak pressure dependence of the combustion rate for a given composition, the linearity of the change in composition of the mixture at a given pressure, as well as the results of thermocouple measurements, give evidence in favor of the hypothesis that inert gases, in diffusing within the flame jet, decrease its temperature. Consequently, the flame propagation rate decreases linearly and at a certain concentration of additive combustion ceases.

Sulimov, A. A., Obmenin, A. V., Korotkov, A. I., and Shushlyapin, P. I. "Low Velocity Regime of Explosive Transformation in Charges of High Density Solid Explosives," 464-469

Sections: E, G

Subjects: Explosive transformations; Solid explosives

Given in the paper is an analysis of the status of the problem, and an attempt is made to explain the results found in the literature and those obtained by the authors from a unified viewpoint on the basis of existing ideas as to the characteristics of propagation of weak (1-20 kbar) compression waves in solid organic materials.

A relationship is obtained between the low-velocity regime of TEN and the pressure in the shell, and it is compared with the dependence of the propagation rate of the compression wave in the pressure wave. The correlation established between the trend of these relations indicates the validity of the concepts developed in the paper. The subsonic, transonic, and supersonic propagation of the low-velocity mode are examined. The compression-wave profile is analyzed at various mode velocities.

Sveltov, B. S., Lur'e, B. A., and Kornilova, G. E. "Investigation of the Transformation of Nitrogen Dioxide When It Interacts with Various Organic Compounds in the Condensed Phase," 780-784

Section: H

Subjects: Nitrogen dioxide; Decane; Octanol; Propanol; Butanoic acid; Butyl butanoate; Diethylene glycol; Glycol dinitrate; Decyl nitrate; Decyl alcohol

The nitrogen dioxide oxidation of decane, octanol, propanal, butanoic acid, butyl butanoate, diethylene glycol dinitrate, decyl nitrate, decyl alcohol, and butylacetal acetaldehyde is studied. The main attention was devoted to the conversion of nitrogen. The kinetics of the process are determined for some of the substances. A tentative comparison of the rates for the first seven compounds yields the following relative values: 1; 10^3; 10^3-10^4; 0.1; 0.2; 0.3; and 0.4, respectively. The alcohol and acetal react almost instantaneously. The interaction rates are close to those observed in vapors.

The relatively slowly reacting materials nitrate primarily to C-nitrocompounds and reduce NO_2 principally to NO. The composition of the products is described satisfactorily by the known radical mechanism. For fast-interacting substances one must also admit the possibility of an ionic development of the process. In this case the reduction of the nitrogen to N_2 is more thorough. The strong disruption of the carbon skeleton of the molecule with the generation of CO and CO_2 is atypical of liquid-phase conversions.

Tesner, P. A., Shraev, B. I., Knorre, V. G., and Glikin, M. A. "Influence of Explosive Decomposition of Acetylene on the Properties of the Resulting Carbon Black," 725-728

Section: I

Subjects: Explosive decomposition; Detonation; Acetylene; Carbon black

A study is made of the dispersivity of the carbon black that forms during the slow spontaneous decomposition (burning) of acetylene under constant pressure and during detonative decomposition. Increasing the initial pressure from 2 to 10 atm during burning leads to an increase in the specific surface area of the carbon black (from 30 to 80 m^2/g) and in the flame temperature.

In the case of detonation, the velocity of stationary propagation of the explosion is about 2000 m/sec, while the specific surface area of the resulting carbon black in the initial-pressure interval of from 2 to 26 atm does not change, amounting to about 170 m^2/g. It is concluded that the specific surface area of the carbon black is determined by the temperature of explosive decomposition of the acetylene.

Todes, O. M., Gol'tsiker, A. D., Gorbul'skiy, Ya. G., and Ionushas, K. K. "Propagation of a Plane Flame Front in Aerodisperse Systems," 166-170

Section: D

Subjects: Flame front propagation; Aerodisperse systems

In the development of the papers by Nusselt and Essehigh, a scheme was devised for calculating the velocity of a stable front in aerodisperse systems. The radiant flux from the flame front heats up the air suspension ahead of it to its ignition temperature under the given conditions, making possible steady propagation of the front at velocities from meters to tens of meters per second. The possibility of inhibition of flame propagation in an air suspension is analyzed theoretically and confirmed experimentally.

Tyul'panov R. S., Sokolenko, V. F., and Alimpiev, A. I. "Investigation of the Structure of Hydrogen Diffusion Flames," 318-321

Section: G

Subjects: Diffusion flame, structure; Hydrogen diffusion flame

An experimental investigation was carried out in a broad range of flow velocities (20-180 m/sec) using the Toepler method with an annular knife edge, which made it possible to pick out the density gradients which are governed by temperature variations. It is shown that in many cases the burning of a diffusion flame jet takes place in local zones which are maintained for a considerable period of time. A statistical analysis was made of the experimental data using the Kovazhny method, modified by the authors, for determining the characteristic spatial scales of temperature inhomogeneities from plane Toepler photographs. The analysis of the experiments showed that the characteristic scales of the temperature inhomogeneities correlate with the Lagrangian turbulence scales and have a certain tendency to increase with increasing burn-up. This indicates that burning in a diffusion flame jet is governed by the structure of the turbulent flow.

Tyunyaev, Yu. N., Lisitsyn, Yu. V., Novitskiy, E. Z., Ivanov, A. G., and Mineev, V. N. "Electrical Conductivity of Alloyed and γ-Irradiated NaCl Behind a Shock Front," 591-596

Section: I

Subjects: Conductivity; NaCl, alloyed, γ-irradiated; Shock front

The electrical conductivity of single-crystal NaCl compressed by a plane shock in the (100) direction in the 20-276 kbar pressure interval is determined. The influence of an addition of Ca^{2+} and of color centers of radiation origin (F-centers) on the magnitude and nature of the electrical conductivity is studied. It is found that the F-centers do not affect the electrical conductivity, whereas the introduction of Ca^{2+} increases it appreciably. The electrical conductivity of the NaCl in the direction parallel to the shock front is much greater than in the normal direction. It is concluded that the electrical conductivity is ionic in nature.

Vasil'ev, A. A., Gavrilenko, T. P., and Topchiyan, M. E. "Location of the Chapman Jouguet Surface in a Multifront Detonation in Gases," 481-486

Sections: I, G

Subjects: Detonation in gases; Chapman Jouguet surface

The results of experiments on determination of the boundary of the Chapman Jouguet surface farthest from the front in a detonation wave in gases are discussed in this paper. The meaning of this front is as follows: rarefaction waves arising at distances from the front greater than the distance to this boundary do not affect the velocity of the detonation wave. It is found that this boundary is located at a distance of from 3.6 to 10 units from the front depending on the mixture. A numerical calculation was made which shows that the calculated Chapman Jouguet plane is much closer than the experimentally found trailing edge.

Vinokurov, A. Ya., Kudryavtsev, E. M., Mironov, V. D., and Trekhov, E. S. "Investigation of Vibrational Relaxation of Carbon Monoxide," 690-693

Section: I

Subjects: Carbon monoxide; Vibrational relaxation

Given are the results from an investigation of the vibrational relaxation of carbon monoxide for the case of instantaneous heating of pure CO to temperatures of 1500-3000°K in an incident shock wave. The main band at $\lambda = 4.66\ \mu$ and the first harmonic at $\lambda = 2.34\ \mu$ were recorded. The experimental results demonstrate that a step-like mechanism dominates at a population of $v = 2$. A temperature dependence of the CO vibrational relaxation time in the initial portions of the relaxation zone was obtained.

Vodyankin, Yu. I., Dubnov, L. V., and Maurina, N. D. "On the Mechanisms of Initiation of Explosives by Friction," 511-514

Section: B

Subjects: Explosives, initiation; Initiation by friction; Ignition; Detonation; Transitions; Deflagration to detonation

Some quantitative characteristics of a proposed local themal method of initiating explosives by friction are verified experimentally. The relationships found between the initiating pressure and the magnitude of the suspension confirm the proposed mechanism, according to which the initiation of explosives is governed in the first approximation by the conditions of attainment of mechanical instability and brittle rupture by a plastically deformable volume of explosives. It was found that, at certain rates of friction, transition from a low-speed to a high-speed friction regime is observed. For the latter the dependence of the initiating pressure on the magnitude of the suspension is absent. In this case, a considerable weakening of the sonorousness and strength of explosion connected with the corresponding transition at these regimes from deep-seated rupture of the continuity of the explosives to contact rupture is observed for explosives of the ammonium perchlorate type, in which development of explosion from a center is impeded.

Voinov, A. N., Nechayev, S. G., and Turovskiy, F. V. "Some Features of Ignition of Gas Mixtures by Incandescent Bodies in the Case of an Engine," 392-395

Section: B

Subjects: Ignition; Incandescent bodies; Engine ignition

Considered is the ignition of a gas mixture by a body which is receiving heat from the outside or is a heat sink. It is shown that in the case of fast periodic variation of the temperature and pressure of the surrounding mixture the critical conditions corresponding to a sharp increase in temperature of the igniting body depend on the rate of supplementary heat supply (heat release). It is pointed out that the dynamics of development of the process are controlled to a considerable extent by the rate of diffusion of the governing component to the reaction zone. The results facilitate finding effective means of combating one of the disruptions of the working process in boosted light-fuel engines, namely, uncontrolled premature ignition.

Voskoboynikov, I. M. "Decomposition of Hexogen in a Detonation Wave," 447-450

Section: G

Subjects: Detonation wave; Hexogen decomposition

Estimates were made of the decomposition times of hexogen in a detonation wave of composite explosives on the basis of an analysis of relations between the detonation rates and the charge diameter. At pressures less than 170 kbars and high dispersivity of the explosive, the decomposition of grains of hexogen takes place mainly from the surface, while with low dispersivity and high pressures it takes place in the form of an adiabatic explosion in a volume. The values obtained for the adiabatic explosion delays are found to be in good agreement with those measured for shock-wave initiation of single-crystal specimens. The rates of

decomposition of hexogen from the surface are estimated at 70 m/sec at 100 kbars and 110 m/sec at 170 kbars.

Voskoboynikova, N. F. "Critical Detonation Diameters of Solutions of Solid Explosives," 474-476

Sections: E, G

Subjects: Solid explosives; Detonation diameters

Given in this paper are the experimental values of the critical diameters (d_{crit}) and velocities (D) of detonation of solutions of some liquid explosives. A proportionality is found between variation of the values of d_{crit} and the products of D_t, where t is the adiabatic explosion lag of exposives at the temperatures reached in the shock front of the detonation wave. In calculation of the adiabatic explosion lags, it was assumed that the leading stage of the reaction is monomolecular decay, the activation energy of which does not change when the material is compressed. This is true not only of cases when the explosive is diluted by relatively inert liquids, but also of solutions of tetranitromethane with hydrocarbons.

Vulis, L. A. "Turbulent Gas Combustion: Outline of the Present Status of the Theory," 265-275

Section: G

Subject: Turbulent gas combustion

Discussed in this survey are the status, principal directions and probable outlook for the development of the theory of turbulent combustion of gases. An intimate relationship is shown between these aspects and the general theory of turbulent motion with shear, the great value of experimental investigation of the pulsation structure of a flame jet, and modern methods of numerical computation. The greatest attention is devoted to the aerodynamic theory of a turbulent gas jet. Briefly outlined are new works in the field of semi-empirical turbulence theories and some results of a model numerical experiment.

Vulis, L. A., Kuznetsov, O. A., and Yarin, L. P. "Investigation of the Aerodynamics of the Turbulent Flame Jet of a Homogeneous Mixture," 330-336

Section: G

Subjects: Turbulent flame aerodynamics; Homogeneous gas mixtures

The results of a detailed experimental investigation of the aerodynamics of a turbulent flame jet of a homogeneous mixture of gases are presented. The characteristic jet structure of the flow is determined; the distribution of the dynamic pressure, velocity and temperature is constructed, as is the pattern of the stream lines, isotherms and isobars for a direct and inverted flame jet under conditions

of natural free stream turbulence and turbulence increased by means of a mechanical turbulence generator. The possibility of an approximate calculation of a flame jet by the method of the equivalent problem of the theory of thermal conductivity is demonstrated, the location of the flame front being found from experiment.

Yakusheva, O. B., Yakushev, V. V., and Dremin, A. N. "Formation of Sulfur Particles in Sodium Thiosulfate Solutions Behind a Shock Front," 544-548

Section: H

Subjects: Sulfur particles; Sodium thiosulfate; Viscosity; Coagulation of particles

A study is made by the high-speed solar photography method of colloid formation for aqueous solutions of sodium thiosulfate in the 5-500 g/*l* concentration range with 80-150 kbar impact compression. It is shown that the sulfur released by shock compression coagulates, leading to the appearance of a yellowish color and subsequent loss of transparency upon increase in particle size. On the basis of Smolukhovskiy's coagulation theory an estimate is made for the viscosity of water under impact compression.

Yakushev, V. V., Nabatov, S. S., and Dremin, A. N. "High-Frequency Methods of Measuring the Dielectric Properties of Condensed Materials Behind a Shock Front," 584-590

Sections: N, I

Subjects: Dielectric properties; Shock front

Two high-frequency methods are proposed for measuring the dielectric properties of condensed materials behind a shock front, an amplitude method and an oscillatory loop method, based on measuring the condenser capacity with the dielectric being studied under the conditions of a single shock compression. In the amplitude method the capacity is determined from the magnitude of the amplitude of the fall-off in high-frequency voltage across the condenser, while in the oscillating loop method it is determined from the eigenfrequency of the dielectric oscillations.

A theoretical foundation is given for the two methods which takes into account the dispersion properties of the dielectric permittivity and the electrical conductivity of the material.

Measured are the dielectric permittivity and polarization relaxation times of nitrobenzene behind a shock front of 30-100 kbar intensity. It is found that the low-frequency dielectric permittivity of nitrobenzene increases approximately in proportion to the compression of the substance.

Yalovik, M. S. "Dissociation of Molecular Nitrogen in the Absence of Vibrational Equilibrium," 698-701

Section: H

Subjects: Dissociation; Nitrogen; Vibrational disequilibrium

An experimental study is made of the influence of a difference in vibrational (T_k) and translational (T) temperature in the dissociation zone on the rate constant of dissociation. The formula

$$k_d(T) = k_d(T,T_k)\frac{T_k}{T}\exp\left[-\frac{D\text{-}3RT}{R}\left(\frac{1}{T}-\frac{1}{T_k}\right)\right]$$

is proposed for transition to values of the constant dependent only on the translational temperature. The expression for the nitrogen dissociation rate constant upon collision of a nitrogen molecule in the 6000-17,000° K temperature interval has the form

$$k_k^{N_2}(T) = 3.4 \cdot 10^{14\pm 0.18}\sqrt{T}\exp(-D/RT)\text{cm}^2/\text{mol-sec},$$

where D is the dissociation energy of the nitrogen.

Yampol'skiy, Yu. P., Maksimov, Yu. V., Korochuk, S. I., and Lavrovskiy, K. P. "The Use of Deuterated Compounds to Study the Kinetics and Mechanism of Thermal Conversions of Hydrocarbons," 650-653

Section: H

Subjects: Kinetics; Reaction mechanisms; C_2D_2; D_2; CD_4; Pyrolysis; Hydrocarbons; Cracking

The introduction of deuterated compounds into a reacting system made it possible to study the mechanism of high-temperature reactions of thermal decomposition of acetylene and cracking of ethane. In studying the thermal decomposition of C_2D_2 and the pyrolysis of C_2H_4 in the 750-950°C temperature interval, it is shown that the reaction takes place by the detachment of molecular hydrogen from the acetylene on the surface. The concentrations of atomic hydrogen in the cracking of pure ethane and of ethane in the presence of inhibitors (isobutylene and propylene) were measured in the 700-900°C temperature interval by adding CD_4 and D_2.

Zakharenko, I. D. and Mali, V. I. "Viscosity of Metals in the Case of Explosive Welding," 575-578

Section: I

Subjects: Viscosity of metals; Metal viscosity; Explosive welding

The oblique collision of plates during explosive welding is considered, in the initial stage, to be the collision of jets of ideal liquid, with allowance for viscosity in the flow behind the contact point. From the generalized Stokes equation the viscosity is found to be inversely dependent on the displacement of the particles

in the direction of the velocity of the point of contact. Using this relationship and experimental measurements of the residual displacement of particles of prefixed lines in specimens, estimates are obtained of the viscosity coefficients for aluminum, copper, steel, niobium, titanium, and lead. The results are compared with the existing literature data.

Zarko, V. E., Mikheev, V. F., Orlov, S. V., Khlevnoy, S. S., and Chertishchev, V. V. "Features of Hot Gas Ignition of Powder," 34-37

Section: B

Subjects: Hot gas ignition; Powder ignition; Ignition by hot gas, of powder

A study is made of the characteristics of ignition under the conditions of conductive and convective heat transfer from a hot gas, and the domains of applicability of thermal theory are defined. The research objects were nitroglycerin powder N and extruded nitrocellulose. It is shown that for substances with a complex reaction mechanism (in the solid and gas phases) there exists a range of conditions in which ignition is governed predominantly by the parameters of the solid-phase reactions. Suppression of the gas-phase reactions is achieved under the conditions of conductive heating, that is by pressure increase (owing to stabilization of the reaction mixture by an inert gas); under conditions of convective heating; i.e., by intense removal of the gaseous decomposition products by a high-speed gas flow. The second method of heating is less suitable for the study of nitroglycerin powders and other explosives whose melting (softening, liquefying) temperature is below the ignition temperature.

Zaslonko, I. S., Kogarko, S. M., Mozzhukhin, E. V., and Demin, A. I. "Vibrational Activation in Exothermic Decomposition Reactions," 689-693

Section: I

Subjects: Energy chains; Hydrogen azide; N_2O; Vibrational activation; Decomposition

A study is made of vibrational non-equilibrium in the thermal decomposition of hydrogen azide and nitrous oxide. It is found experimentally that considerable vibrational pumping of the original molecule occurs, providing "energy feedback," and as a result the reaction has the main features of a chain process. The specifics of vibrational pumping of the original molecules imply the possibility of explosive auto-acceleration of decomposition at a sufficiently high rate of gas temperature decrease.

Zenin, V. I. and Vaynshteyn, B. I. "Particular Features of Manifestation of the Channel Effect in Coarsely Dispersed Explosives," 477-480

Section: G

Subjects: Dispersed explosives; Explosives, coarsely dispersed; Channel effect, dispersed explosives

The results of an investigation of the channel effect in coarsely dispersed explosives consisting of large grains are discussed. The particular features of the manifestation of this effect in such explosives are noted as compared with a powder. A channel-effect mechanism is proposed for coarsely dispersed explosives which explains these features.

Zhernokletov, M. V. and Zubarev, V. N. "Determination of Isentropes of the Expansion of Substances after Impact Compression," 565-568

Section: I

Subjects: Isentropes; Impact compression; Teflon; Paraffin; Ice

A method is proposed for determining the pressure-density relationships in the case of adiabatic expansion of substances from states behind a shock front. The initial experimental data for the subsequent determinations were profiles of the mass velocities in the rarifaction waves. The latter formed when relaxation spread within the specimen after a plane shock wave reached the free surface. The mass velocity was recorded as a function of time by a pickup mounted in the specimen under study when it moved in a magnetic field. The results of determining the adiabats of the expansion of teflon, paraffin and ice are presented. Estimates of the residual energies and volumes are given for a fall-off in pressure of from ~100,000 to 100 atm.

Zimont, V. L., Ivanov, V. K., and Oganesyan, S. Kh. "Self Ignition and Collapse of Combustion in the Stagnation Zone During the Flow of a Supersonic Stream of a Combustible Mixture Past a Plane Step and a Depression," 386-391

Sections: B, E

Subjects: Self-ignition; Combustion collapse; Stagnation zone; Supersonic stream

On the basis of the thermal mechanism and of a gas-dynamic model of the flow, the critical conditions of collapse of combustion in the stagnation zone formed during the flow of a combustible mixture past a step and a depression are given. The critical conditions of self-ignition were investigated on the basis of thermal and chain mechanisms. The experimental results of investigating mass transfer in such stagnation zones are discussed for flows at $M = 2.5$. Comparisons of the calculated volume with experiment are given, as are examples of numerical calculations of the critical conditions for hydrocarbon-air and hydrogen-air mixtures.

MEETINGS

Air Force Office of Scientific Research, Combustion Kinetics Contractors Meeting, 1975, Compilation of Abstracts, Interim Report 4-5 September 1975, School of Aerospace and Mechanical Engineering, Princeton University under Contract No. AFOSR 74-2604 for The Air Force Office of Scientific Research, Arlington, Virginia, 32 pp. (September 1975)

Subjects: Chemical kinetics; Combustion; Plume research

This report is a collection of the abstracts of talks given by contractors and grantees of the Air Force Office of Scientific Research (AFOSR) in the area of chemical kinetics related to combustion, plume and wake technologies at a meeting held at the Air Force Armament Laboratory, Eglin AFB, Florida, 4-5 September 1975.

CONTENTS:

"Infrared Radiation Simulation Processes," D. B. Ebeoglu (AFATL, Eglin AFB)

"Interpretation of IR Radiation Plume Data on Subscale Kerosene - O_2 Motors," H. S. Pergament and R. D. Thorpe (AeroChem Research Laboratories, Princeton, New Jersey)

"Kinetics Interest of Air Force Rocket Propulsion Laboratories," J. D. Stewart (AFRPL/DYSP, Edwards AFB)

"Vibrational Relaxation Studies in CO_2, N_2O, and H_2O Using a Tunable Infrared Laser," J. Pinzi (University of California, Berkeley, California)

"Collisional Excitation of Radiative Vibrational Modes in Some Simple Polyatomic Molecules," R. Subbarao (Yale University, New Haven, Connecticut)

"Research Topics in Turbine Combustion Technology," T. J. Rosfjord (AFAPL, Wright Patterson AFB)

"Oxidation Kinetics of Hydrocarbon Fuels," F. L. Dryer and I. Glassman (Princeton University, Princeton, New Jersey)

"Models for the Combustion of Acetylene and the Concurrent Destruction of NO_x," E. H. Ressler and S. H. Bauer (Cornell University, Ithaca, New York)

"Rate Constants of Elementary Steps in Hydrocarbon Oxidation," R. R. Baldwin and R. W. Walker (The University Hull, England)

"Absolute Rate Constants of Some Key Combustion Reactions," S. W. Benson and F. Zabel (Stanford Research Institute, Menlo Park, California)

"The Thermal Pyrolysis and Oxidation of Methylamine," R. F. Sawyer and O. I. Smith (University of California, Berkeley, California)

"Kinetic Reaction Coefficients in Rocket Exhaust Plumes," W. R. Snow (University of Missouri, Rolla, Missouri)

"Alkali Halide Shock Tube Measurements," A. Mandel (Avco Everett, Everett, Massachusetts)

"IR Spoofing by Particulate Addition to Wake Flows," G. E. Caledonia (Physical Sciences Inc., Wakefield, Massachusetts)

"Interfacial Chemical Reactions in Flow Systems," D. E. Rosner (Yale University, New Haven, Connecticut)

"Properties of Relevant High Temperature Molecules," W. Weltner, Jr. (University of Florida, Gainsville, Florida)
"Carbon Particle Formation by Condensation of Carbon Vapor in a Flowing Inert Gas," D. M. Mann (Aerodyne Research Inc., Burlington, Massachusetts)
"Low Pressure Metal Vapor Oxidizer Flames," I. Glassman and D. W. Naegeli (Princeton University, Princeton, New Jersey)

Conference on Arson and Incendiarism, July 29-30, 1975, Committee on Fire Research, National Research Council, National Academy of Sciences, Washington, D.C.; Chairman J. W. Kerr

Agenda

Keynote Address - Dr. C. W. Walter, Chairman, Committee on Fire Research

Introduction - J. W. Kerr, Conference Chairman

Fire Chiefs Panel and Discussion - Chairman, Chief E. Stanley Hawkins
Panel, Dan J. Carpenter, Alcus Greer

Behavioral Panel and Discussion - Chairman, Dr. W. Moretz
Discussion, Dr. Nils Wiklund

Arson Investigation Panel and Discussion - Chairman, J. E. Stuerwald
Panel, R. E. May, Lt. W. R. Rucinski

Discussion Groups I. Operational Working Group - Chairman, Chief E. S. Hawkins
II. Human Factors Working Group - Dr. W. Moretz
III. Legal and Legislative Working Group - Chairman, J. E. Stuerwald

Conference Report "Incendiarism: An Overview and An Appraisal - J. W. Kerr

INCENDIARISM: AN OVERVIEW AND AN APPRAISAL

It is the purpose of this paper to report on a brief seminar on incendiarism held at the National Academy of Sciences, July 29-30, 1975, to summarize the findings of that gathering, and to recommend a course of action. The Committee on Fire Research planned and conducted the seminar and prepared this report.

BACKGROUND

Long a subject of concern to the fire community in general and the Committee on Fire Research in particular, incendiarism (especially its most visible manifestation—arson) has proved intractable as a study topic and unwieldy as a focus for interdisciplinary examination. Uninformed though we might feel regarding some aspects of combustion, of fire development, and even of fire suppression, we are by contrast almost illiterate regarding most important facets of incendiarism, and simply ignorant as to most behavioral factors. Statistics are at best conflicting;

at worst they are false if not falsified. Jurisdictional disputes are the rule, and even innocuous speculation (much less the making of pronouncements) is shunned by the medical profession. While investigative methodology is making some progress, most other areas are not. As a result, the proliferating arson-oriented meetings tend to involve the same people saying the same things to each other. Pursuit of the "why?" of the problem continues to languish.

Hence this attempt to bring together the three major professions in the field—behavioral (medical), suppression (fire chiefs), and criminological (arson investigators). It is time to ask ourselves whether or not we really understand anything about arson and incendiarism. Can we get quantitative about it, or can we just continue to be descriptive? What are the stumbling blocks of fire suppression people and of arson investigators and of behavioral people? Are the data good or bad, and is there any hope for upgrading? Are the data really slanted as by calling arson deaths something other than murder? Who should be trained to do what and how?

Finally, as we explored the problem areas we concluded that, while a small gathering to assess the situation was necessary, timely, and feasible, we could not be certain that a major National Academy of Sciences symposium on the subject was to be viewed so sanguinely. Hence, the second and practical question: Should we recommend a major symposium and, if so, when, where, and of what scope?

FINDINGS

As a result of some 17 hours of discussion within the span of only 28 hours, a number of responses to the foregoing can be formulated. The following pages reflect the papers, the comments, and the debates. The general statements enjoy broad if not fully unanimous support; some of the more detailed remarks juxtapose several—at times divergent—points of view.

Perception of "incendiarism" by various groups and subgroups of people covers an almost incredibly wide range. Webster simply equates it with "arson," whereas others broaden it to include innocent playing with matches. It would seem appropriate, therefore, to promulgate an agreed-upon definition or series of definitions in order to facilitate unambiguous communication and then to form action programs appropriately. In this paper we use "incendiarism" in the broadest possible sense and restrict "arson" to the classical usage of setting fires for gain or malice.

This lack of focus tends to obscure the true or perceivable cost of incendiarism, because the attribution of origin of fire events is ambiguous. There rarely surfaces in the awareness of the public the fact that a vast number of fires go listed as "undetermined origin" or, worse yet, "unknown." Terminology itself is a stumbling block, but even conservatively lumping together arson, potential arson, probable incendiarism, and undetermined origin, we can come up with a total of about half the fires in the United States, for a total damage of 5 to 6 billion dollars per year. This total, which seems valid as a general summation, although not subject to strict audit at the moment, would make incendiarism (certainly) or arson (very probably)

the single largest source of unwanted fires in the United States or perhaps in the world. This fact, too, is obscured in the public view by the more customary quotation of the figure for "definitely arson" losses; itself a large and provocative total, it still is not so gripping a statistic as the likely 50% just cited. By whatever yardstick, arson is on the upswing, yet public awareness of arson is low, and public motivation to reduce the total is even lower.

Apathy is not the precise term to describe this attitude, if we are to believe the polls conducted on similar topics. Nobody is really unconcerned about arson; they all agree that it is a problem that needs work. They just believe somebody else is working on it.

Within the public safety community (police, fire, and related programs) there is again a considerable variation of point of view. Law enforcement officials at all levels seem prone to regard arson as the fire departments' problem. Ambivalence in the fire service itself has not helped clear this up. Among others, the motives for passing the buck include the desire to have better statistics (and hence public image) about one's own group, the need to cut budgets, and the desire to avoid tackling a messy problem. Listing of major crimes by the Federal Bureau of Investigation does not include all felonies in the mandatory section of the statistics program; hence arson (a felony) and arson-related fire deaths (murder) do not necessarily reflect poorly on either group. Such shirking of responsibility does not contribute to the solution. We note that the most classically, unequivocally heinous crimes—arson and treason—receive scant attention by data people.

It is in the budgetary field that reduction of incendiarism can run into problems within the fire community itself. Most major fire department budgets are controlled by the fire suppression forces. Manpower costs are likely to run 90% of such budgets, and when decisions are made on additional hardware and reduced manpower, arson bureaus are frequent victims. In various cases cited, there has been total uniformity as to consequence: Reduce arson investigators and investigations and watch arson increase at once.

Facilitation of investigation of the source or origin of a given fire is an inhibition on optimal suppression of going fires. The reflex of the first firefighters on the scene is to put out the fire, not to preserve evidence. We cannot urge firefighters to ignore threats to life, or likely fire expansion, but it would appear that modification of procedures (and of relevant training) would be in order.

The role of fire prevention in reduction of incendiarism appears to be largely in the educational field, with the general public and particularly with juveniles. Our culture tends to make fire in general attractive, whether it be blowing out the birthday candles or helping Daddy start the barbecue, not to mention spectator events such as bonfires, rallies, pyrotechnics, or running fire apparatus. Respect for fire and its potential is an often neglected educational topic.

Fire marshals in many cities and states are charged with both prevention and investigation; in many cases they report to the fire chief, who tends to be oriented toward fire suppression. Even when this is not the case, the dichotomy risks being dysfunctional. However set up, the marshal tends to concentrate on arson investigation, and it is here that the system has the greatest potential for failure. Conflicting laws and division of responsibility, coupled with manpower and operating

budget cuts, can lead to drastic neglect of the crime of arson, of its investigation and prevention, and of the public measures required to cope with it.

Investigation of the origin of fires is a basic requirement. In some large cities such checks are routine; in rural areas, particularly those served by suppression-oriented volunteers, arson investigation devolves onto state-level authorities, meaning usually too little and too late. In every case cited, vigorous and consistent investigations led to reduced incidence of arson, whereas reduction of the investigative staff was followed by an increase in arson-attributable loss.

Insurance-supported arson investigators functioned well, but that structure has long since been disestablished. Some insurance-sponsored work continues, but it appears that only publicly funded programs can develop major impact from now on. A full systems analysis relating loss, suppression, and investigation costs and other important factors is urgently needed if prevention and control of incendiarism is to progress. There are perhaps 6,000 arson investigators in the United States today; how many is "enough," and how should they be used?

From the point of view of the medical profession, incendiarism is perhaps less structured overall, although more minutely described. Hospitals suffer from the same problem as do fire suppression forces: arson calls reduce availability of forces and delay responses. They also need to foresee and cope with internal arson and carelessness and childish (or senile) acts.

Behavioral aspects, however, take the lead in demanding medical attention to incendiarism. An extremely broad grouping of people who light fires or cause them to be lit are generally accepted as being motivated at least in part by emotional problems or mental deficiencies. The general state of knowledge in such matters is relatively undeveloped. Research has not had the benefit of large samples, and virtually all of the samples studied have been selective; that is, the patients or inmates were already diagnosed as "arsonists" or some related term. There is thus a pressing need to explore the social, cultural, demographic, value-judgment, and attitudinal profiles of people involved with set fires and the epidemiology of the acts. A major problem impeding communication among researchers is taxonomy; even the structures partly accepted so far do not cover such obvious cases as the person who hires the actual arsonist. There is still disagreement over whether or not an incendiarist is in some way "sick." For many, setting fires is a final-type action, not a means to an end; for others, it is quite obviously a part of movement toward a goal. For some, punishment or its threat is a deterrent; for others, the "reward" of a successful fire-setting may be enough to tend toward terminating such conduct.

CONSENSUS ON FINDINGS

Within the formulation in the foregoing paragraphs, we find a consensus in the following areas:

Data

- Terminology is not uniform.
- Collection forms and practice are not coordinated.

- Collation is rudimentary.
- Interpretation is subject to question.
- Dissemination is unstructured.

Training

- Content of training material is reasonably understood.
- Need for training is not fully documented.
- Levels of need are widely accepted.
- Funding of training programs is spotty.

Laboratories

- Crime laboratories are overworked.
- Arson laboratories could fill some gaps.
- Gaps are not yet documented.

Staffing

- Arson investigators are needed at all levels.
- Optimum numbers have not been defined.
- Relationships between investigators and other public safety people are not well defined.
- Where staffing declines, arson increases.
- Where investigation (leading to indictments, arrests, trials, and some convictions) rises, arson declines.

Research

- The great aching void is in the behavioral area.
- A full-level professional systems analysis (including cost-benefit study) is sorely needed, to eliminate undesirable intuitive judgmental factors.

Major *disagreement* persists as to these points:

- Delivery of arson investigation services outside major municipal environments—how and who.
- Police and fire department boundaries in incendiarism affairs.
- Mental "sickness" matters as related to incendiarism, as a decision point.
- The overall action program mandated by our understanding of the problem and the conflicting performances of major actors in the system.

AN INCENDIARISM SYMPOSIUM IN 1976?

Responses of the conferees to the direct "yes or no" questions of holding a symposium ranged from "yes" to "no," with a strong showing of "maybe's" in the center or more likely on the edges. Negative voices stressed the point that the state of the art is well exposed to technical people in numerous events, such as classes for arson investigators. They felt that another introspective gathering would be pointless.

On the other hand, many people who are uneasy about the lack of structuring of the problem and of research in the area of incendiarism felt that a major symposium under prestigious aegis could only serve for good.

Qualified observations stressed the need for continuity (periodic discipline-oriented conferences), analysis (small problem-oriented study groups), and relevance to actions inside and outside the incendiarism area (new federal agency programs in fire and law enforcement, for example). Some uncertainty as to the role and mission of the National Academy of Sciences in technical areas was also evident among invited participants.

It is the firm conclusion of the Committee on Fire Research that the very uncertainties cited serve to underscore the need for a properly pitched conference on incendiarism within the next 10 to 12 months at the National Academy of Sciences in Washington. That symposium should

- Review the state of the art of detection, investigation, and prevention of incendiarism in a depth not attainable in our 1½-hour sessions per discipline;
- Review action programs in related areas;
- Stress pursuit of knowledge in areas singled out here as deficient; and
- Emphasize behavioral interfaces with other segments of the problem.

Funding, staffing, and solicitation of participation should be undertaken at once by the National Academy of Sciences, using the Committee on Fire Research as a pivotal executive but non-exclusive group.

"Fire Casualties" Conference and Workshop, May 28-29, 1975, Applied Physics Laboratory, The Johns Hopkins University, RANN National Science Foundation, Proceedings to be published.

Program

Opening Remarks - W. G. Berl, JHU/Applied Physics Laboratory

Welcome - A. G. Schulz, JHU/Applied Physics Laboratory

"The APL Fire Problems Program in Perspective," R. M. Fristrom, JHU/Applied Physics Laboratory

"General Organization and Problems Involving Fire Casualty Studies," B. M. Halpin, JHU/Applied Physics Laboratory

"Investigation of Fatal Fire Scenes," J. C. Robertson, Fire Marshal, State of Maryland

"Autopsies and Their Contribution to Understanding Fire Fatalities," R. A. Fisher, Medical Examiner, State of Maryland

"Special Study on Pre-Existing Heart Disease and the Fire Fatality," R. A. Fisher

"Toxicology and the Fire Fatality," Y. H. Caplan, Chief Toxicologist, State of Maryland

"Measurement Techniques for Blood Cyanide in Fire Fatalities," R. Altman, Medical Examiner's Office, State of Maryland

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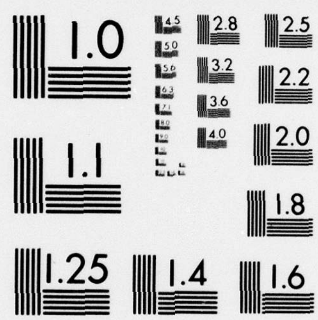

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

"Biochemical and Chemical Analyses in Support of the JHU/APL Fire Casualty Program," W. G. Berl, JHU/Applied Physics Laboratory
"JHU/APL Fire Fatality Program Data," B. M. Halpin, JHU/Applied Physics Laboratory
"Sleep and Arousal Problems," J. C. Gillin, National Institute of Mental Health
"Human Response in Stress Situations," E. Quarantelli, Disaster Research Center, Ohio State University
"Detection and Warning," R. Bright, U.S. National Bureau of Standards
"The National Fire Prevention and Control Administration," J. E. CLark, NFPCA
"Acute Exposure to Fire Atmospheres: Project Smoke," E. P. Radford, The Johns Hopkins University School of Hygiene and Public Health
"Fire Casualty Evaluation - Studies on Civilian and Firefighter Exposures," M. Levine, The Johns Hopkins University School of Hygiene and Public Health
"Data Systems and Fire Casualty Information," J. Slater and M. Birky, U.S. National Bureau of Standards
"The FAA Toxicity Experiments and Cyanide Studies," P. P. Smith, Federal Aviation Authority, Civil Air Medical Institute
"Utah University Toxicity Program," J. H. Petajan, School of Medicine, University of Utah
Workshop Reports and General Remarks, R. H. Long, National Science Foundation RANN Program Director

National Conference on Master Planning for Community Fire Protection, October 28-30, 1975, Orlando, Florida, National Fire Prevention and Control Administration, Department of Commerce

Program

Conference Opening - D. A. Lucht, Deputy Administrator NFPCA
K. Long, Chief Engineer, Los Angeles City Fire Department
B. Chaney, Chief, Mountain View Fire Department

"The Role of the Fire Fighter in Community Fire Protection Master Planning," H. McClennan, President, International Association of Fire Fighters
"The Role of the Fire Department Administrator in Community Fire Protection Master Planning," J. Hurley, President, International Association Fire Chiefs
"The Role of City Management in Community Fire Protection Master Planning," R. DeLong, City Manager, Mountain View, California
"The Role of the Planning Department in Community Fire Protection Master Planning," A. Eastern, Dade County Planning Department, Dade County, Florida
"Is There a Role for Standards in Community Fire Protection Master Planning," M. Grimes, Director, Public Protection, National Fire Protection Association
"Regional Aspects of Fire Service Planning," Dr. P. Jurket, Chief, Transportation Analysis Division, Stevens Institute of Technology

"Planning for Fire Station Location," M. Hendrix, Chief Dallas Fire Department

"Description of the NFPCA Master Planning Methodology," Los Angeles City Fire Department, Mountain View Fire Department, and Mission Research Corporation

"A General Review of NFPCA Planning and Research Activities," Dr. J. E. Clark, Director of Operations, National Fire Prevention and Control Administration

"Fire Protection Master Planning for Disney World," T. M. Moses, Walt Disney, Inc. Conference Summary, H. D. Tipton, NFPCA Administrator

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